The meatification and re-meatification of diets:

The unequal burden of animal flesh and the urgency of plant-meat alternatives

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TINY BEAM FUND

Guidance Memo
August 2021

[1] Sources for images: AgeFotoStock (2021); Dreamstime (2021); Furtseff (2021); Hopkins (2020); Masterfile (2021); Stephanie (2021); Terazono (2019).

Abstract

This Guidance Memo provides a comparative analysis of the production and consumption of animal flesh in six important and illustrative countries, as a basis for assessing the potential of rising plant-meat production and consumption. A core argument is that a rapid and radical transition away from animal flesh-centered diets is an urgent environmental priority, starting in the world's wealthiest countries where per capita consumption is highest, followed by middle income countries where per capita consumption is rising fastest. Another related argument is that plant-meats could have a crucial role speeding this dietary transition, although they do not comprise a proverbial silver bullet. The ultimate aim of this memo is to help environmental and animal advocates appreciate the context and dynamism of plant-meat development, which in turn leads to insights about messaging and how to support growth and direct substitution in diets—what we refer to as re-meatification—moving forwards.

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Glossary of Terms

Big five—the primary domesticated animal species used in livestock production on a world scale: cattle, pigs, chickens, sheep, and goats.

Carbon reservoir—the various spaces (oceans, atmosphere, soils, living organisms, rock crust) where carbon molecules in, and out of, are stored for varying lengths of time; a central factor in climate change is the de-stabilization of the balance of different reservoirs, through the burning of fossil fuels, deforestation, soil degradation, and the loss of biodiversity.

Concentrated animal feeding operations—enclosures that produce large populations of livestock animals in hyper-controlled environments.

Ecological hoofprint—a conceptual framework for assessing the multidimensional resource budgets and pollution loads associated with industrial livestock production.

Enteric fermentation—the digestive process in ruminant animals through which they break down carbohydrates, which results in methane emissions, principally through belching and secondarily through flatulence.

Eutrophication—the depletion of oxygen in bodies of water resulting from the growth and decay of algal blooms caused by excess nutrient loads (primarily of phosphorus and nitrogen); it is frequently fatal to aquatic life and characterized by 'dead zones.'

Feed conversion ratios—the variable rates at which animal bodies convert feed into outputs of flesh, milk, and eggs.

Feed crops—crops that are grown to feed livestock animals, primarily coarse grain (e.g., corn and barely) and oilseeds (e.g., soybeans).

Flexitarian—a dietary identity that is premised on a conscious reduction of meat consumption, though to a highly subjective degree and with a refusal to fully abstain.

Greenhouse gas—a molecule (e.g., water vapour, carbon dioxide, methane, nitrous oxide) that exists in varying concentrations in the atmosphere which absorbs some of the energy from the earth's surface before it is re-radiated to space; different greenhouse gases have different heat-trapping capacities per molecule.

High-income country—a World Bank category for countries that had a per capita gross national income greater than $12,615 in 2020.

Low-income country—a World Bank category for countries that had a per capita gross national income less than or equal to $1,035 in 2020.

Lower middle-income country—a World Bank category for countries that had a per capita gross national income between $1,036 and $4,085 in 2020.

Meatification—the movement of meat from the periphery to the centre of human diets.

Middle-income country—a World Bank category for countries that had a per capita gross national income between $1,036 and $12,615 in 2020.

Opportunity food loss—the wastage of useable nutrition (relative to a given volume of production) that results from cycling feed crops through animals to produce meat, milk, and eggs.

Particulate matter—the mixture of liquid droplets and solid particles in the air which are capable of penetrating respiratory systems.

Plant-meat—a product that is intended to directly substitute animal flesh by mimicking key characteristics (e.g., taste, texture, and cooking properties), that is achieved through the reconstitution of various plant-based inputs.

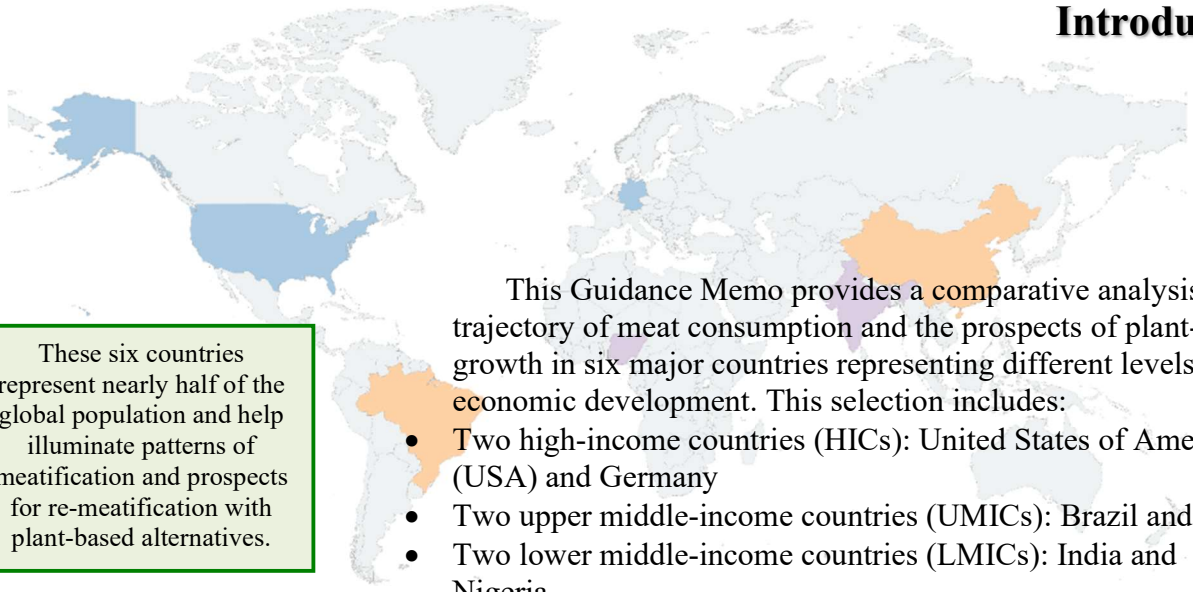
Re-meatification—the direct substitution of plant-meat for animal flesh to an extent that reduces consumption of the latter.

Transnational corporation—a large enterprise with operations in multiple countries which are largely headquartered in high and upper middle-income countries.

Upper middle-income country— a World Bank category for countries that had a per capita gross national income between $4,086 and $12,615 in 2020.

Wet markets—a broad term for a type of marketplace that sells various sorts of perishable goods, including freshly slaughtered animal flesh and fish as well as vegetables and fruits.

Introduction



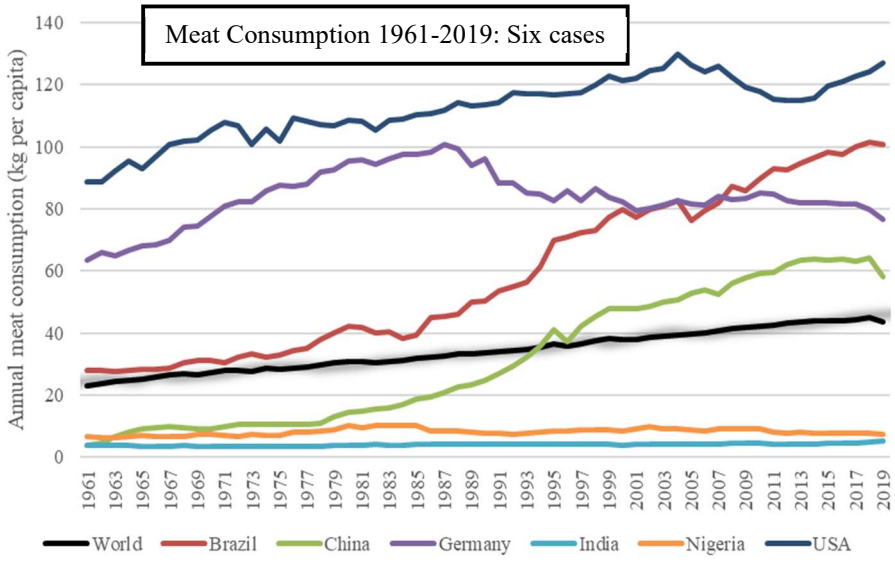
These six countries represent nearly half of the global population and help illuminate patterns of meatification and prospects for re-meatification with plant-based alternatives.

This Guidance Memo provides a comparative analysis of the trajectory of meat consumption and the prospects of plant-meat growth in six major countries representing different levels of economic development. This selection includes:

- Two high-income countries (HICs): United States of America (USA) and Germany
- Two upper middle-income countries (UMICs): Brazil and China
- Two lower middle-income countries (LMICs): India and Nigeria.

These six countries were selected to help illustrate the considerable variation in levels of livestock production and meat consumption that prevail at different levels of economic development, which has important ramifications for the growth of plant-based alternatives. The US and Germany are two of the world's leading producers and consumers of meat on a per capita basis. China and Brazil are at the forefront of aggregate global increases in meat production, with drastically rising per capita consumption in recent decades. India and Nigeria have large and growing populations with levels of per capita meat production and consumption far below the world average.

This group of countries is also noteworthy because it is poised to hold a central role influencing the trajectory of plant-meat production and consumption. Some of these countries have long histories of household plant-meat production, while others are experiencing dramatic increases in consumer demand that is helping stoke production of plant-meat and other plant-based alternatives (e.g., milks, cheeses, and eggs)—although the focus in this Guidance Memo is on meat and plant-meat products.



Source: FAO (2021e, 2021f)

In short, these countries help illuminate the highly uneven character of global livestock production and meat consumption, and the need to contest and reverse this trajectory. The rapid development of plant-meat is a potentially significant response to the multidimensional harms posed by livestock production if these alternatives can grow beyond parallel niche markets and reach levels of broad-based consumer acceptance and substitution for animal flesh—a possibility we refer to as **re-meatification**.

The Meatification of Diets

*The **meatification of diets** describes the shifting place of meat from the periphery to the center of human diets*. The enormity of meatification is reflected in the fact that per capita meat consumption on a world scale has roughly doubled from 23 kg meat/year in 1961 to 44 kg meat/year in 2019, amid dramatic human population growth.[2]

> The assumption that there is a natural or inevitable link between development and increased meat consumption is *highly problematic*.

Meatification is highly uneven, with individuals in HICs tending to consume vastly more meat on average than individuals in less developed countries, while UMICs are at the forefront of rising global consumption. The combination of meatification and population growth led to a *quadrupling* in annual volume of global meat production in just over a half a century.

Virtually all global meat production by volume comes from the **big five** livestock species. While environmentalists have paid a lot of attention to the rising human population, they have tended to give less attention to the fact that the global population of livestock animals has grown even more quickly, and the population of slaughtered animals annually has increased faster still. Many more animals are killed every year than are living at any one point in time because livestock animals are 'turned over' more quickly in industrial systems than in the past.

While meatification is often treated as though it inevitably follows rising wealth, this trajectory is anything but natural. On the contrary, *increasing global meat consumption is not only influenced by consumer preferences and rising effective demand but is also affected by the course of agrarian change and powerful actors in the agro-food system seeking to expand livestock production and absorb chronic grain and oilseed surpluses in pursuit of rising profits*.

There is abundant evidence that indicates reversing the meatification of diets on a world scale is fundamental to prospects of significantly reducing the impacts of agriculture on climate change, biodiversity loss, freshwater consumption and pollution, and other environmental problems. On the current business-as-usual course, greenhouse gas emissions (GHGs) and other adverse environmental impacts from agro-food systems are expected to greatly intensify by 2050, and possibly much sooner, with continuing meatification a central part of this worsening burden.

In contesting meatification, it is important to recognize that the challenge of reversing it is highly differentiated, and that the responsibility to reverse meatification starts in HICs, where per capita meat consumption is the greatest.

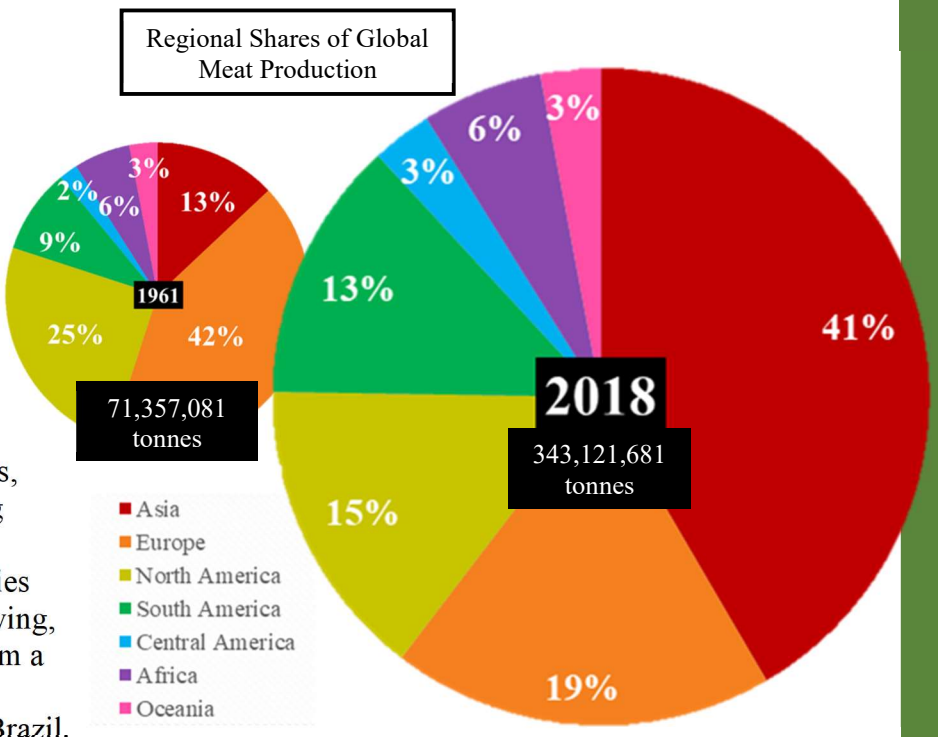
[2] This section is based upon the following sources: Chiles & Fitzgerald (2018); FAO (2021e, 2021f); IPCC (2019); Poore & Nemecek (2018); Ritchie & Roser (2017); Schneider (2013); Simon, 2013; Springmann et al. (2018); Springmann et al. (2016); Weis (2013a, 2015); World Bank (2021).

Livestock Production

Although the total volume of meat produced has increased everywhere, there is considerable unevenness to this growth.[3] The fastest growth has occurred in Asia, where annual meat production leapt from 9 to 144 million tonnes between 1961 and 2018. As a result, while total production in North American and Europe continued rising over this period, their relative shares of global production declined.

There has also been highly uneven growth between livestock species, with global increases overwhelmingly driven by pigs and chickens, the animals whose production is the most heavily industrialized.

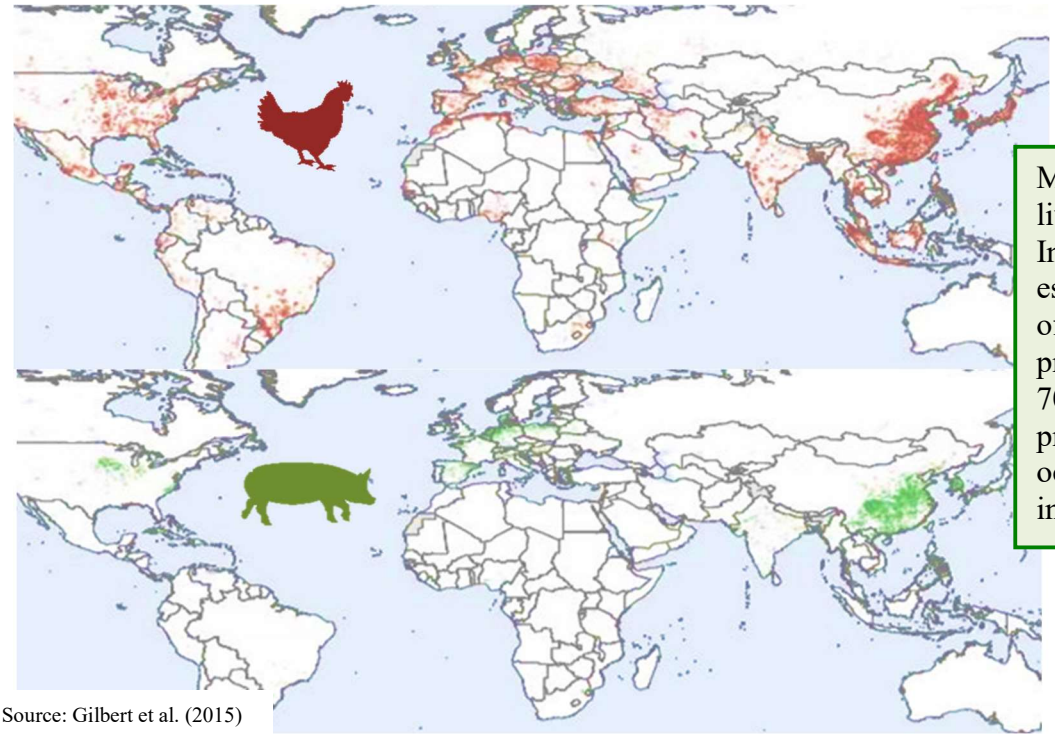
More than 90% of livestock production gets consumed within the country where it was produced, but global trade in livestock products is rising. It is important to note that **feed crops** are heavily traded (primarily corn and soybeans) and have a crucial role in the industrialization of livestock in many countries, most significantly the surging importation of soybeans in China. The number of countries that import feed crops is growing, which are mainly sourced from a small number of exporting countries led by the US and Brazil.



Sources: FAO (2021d, 2021e)

While pasture constitutes the largest land use in the world, increases in global meat production have been overwhelmingly driven by industrial livestock production. Industrialization entails fewer operations producing significantly more animals, whose genetics have been altered to put on weight a lot faster. The combination of density and genetic changes are central to the dramatic acceleration in the time animals move from birth to slaughter. From 1961 to 2018, the population of annually slaughtered animals nearly doubled with cattle, quadrupled with pigs, and grew ten-fold with poultry birds. Animal yields (flesh, milk, or eggs produced per animal) have also increased significantly over this same period. With meat production, yields on a global scale have risen by 39% for cattle, 23% for pigs, and 34% for poultry birds since 1961, although there is considerable unevenness between more and less industrialized systems.

[3] This section is based upon the following sources: Alexander et al. (2016); Berne Declaration & EcoNexus (2013); Chandel et al. (2019); Chemnitz et al. (2014); ETC Group (2015, 2019); FAO (2014, 2021d, 2021f, 2021g); IPES-Food (2017); Kanaly et al. (2010); Ritchie (2017); Ritchie & Roser (2017, 2019b); Sharma (2018); Wang et al. (2018); Winders & Nibert (2004); World Bank (2021).



Maps of intensive livestock systems. In 2010, it was estimated that 57% of all pig production and 65-70% of all poultry production occurred in intensive systems.

Source: Gilbert et al. (2015)

Industrial livestock operations involve the large-scale production of a single animal species guided by the basic objective of mechanizing as many tasks as possible, including the automation of feeding, watering, lighting, and ventilation systems. Increasing industrialization tends to lead to greater geographic concentration of production over time, as operations gravitate toward regions with climatic advantages (e.g., where less energy is needed to regulate temperatures) and favourable regulatory contexts, such as weaker environmental regulations and labour laws.

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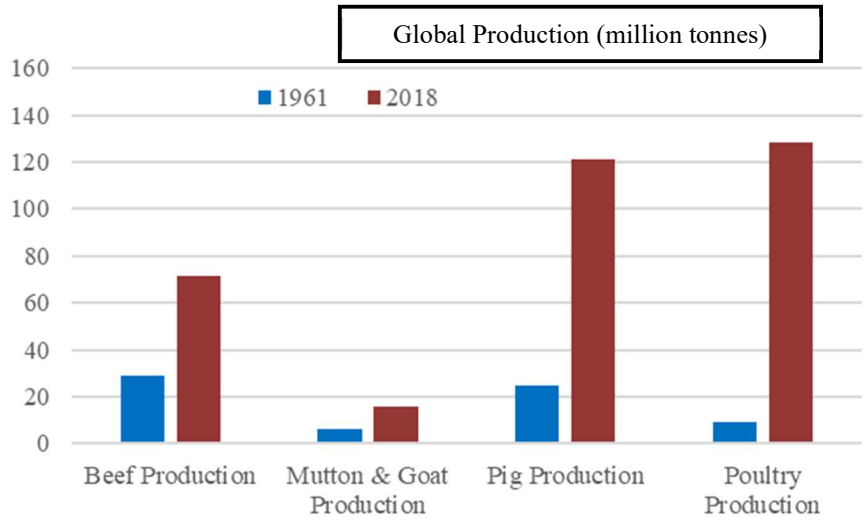
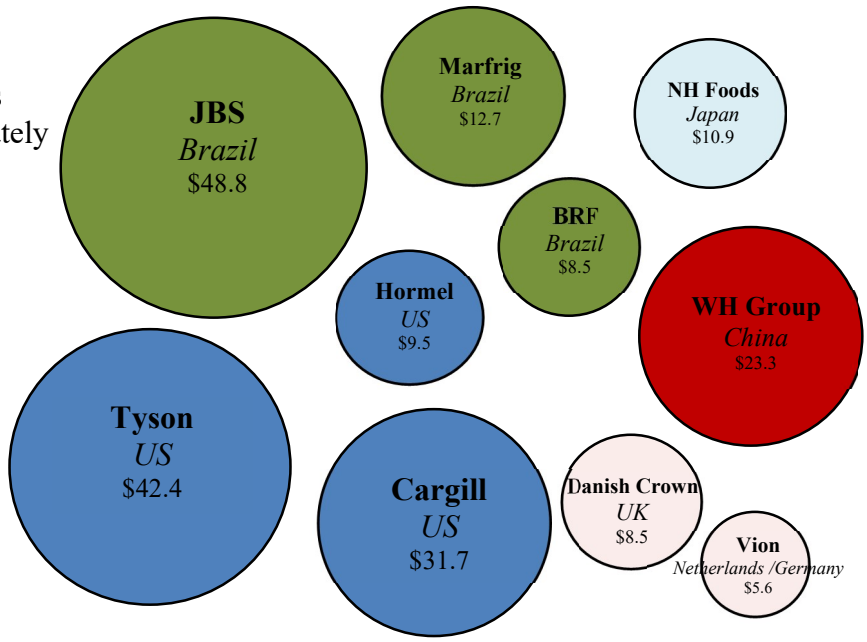


Sources: FAO (2021d, 2021e); World Bank (2021)

There are several extraordinarily large and powerful ***transnational corporations*** *(TNCs) that increasingly dominate livestock slaughter and processing across national borders and exert a great deal of influence over the trajectory of meat production and consumption on a world scale*. For instance, JBS is headquartered in Brazil and has grown to become the world's largest beef and chicken meat processor, with operations in 15 different countries that together slaughter 85,000 cows and 12 million chickens every day. The WH Group is headquartered in China and has grown explosively to become the world's largest pig meat processor. The growth of both JBS and WH Group has included acquisitions of major US-based meat processing TNCs, such as Swift & Company and Pilgrim's Pride by JBS, and Smithfield Foods by the WH Group). The US and Europe are also home to many powerful TNCs engaged in livestock slaughter and processing.

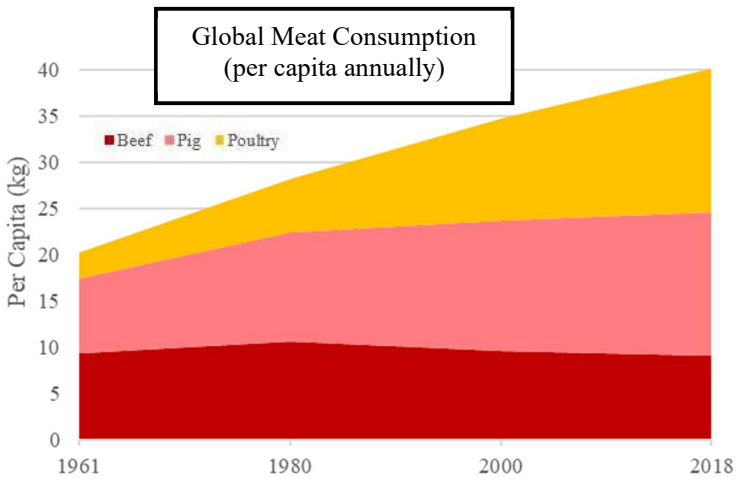
The focus on TNCs should not obscure the importance of government policies and subsidies in the rising production and consumption of livestock. Agricultural subsidies in HICs have long been disproportionately concentrated on large-scale producers, favouring industrialization and the power of TNCs by enhancing markets for various industrial inputs and deflating the prices food processors and retailers have to pay. The subsidized overproduction of grains and oilseeds is a significant factor that has kept the cost of feed—and by extension meat—artificially low, along with the un- and under-accounting of the environmental costs of production.



Sources: Food Engineering (2020); IPES (2017); Sharma (2018).

Meat Consumption

As indicated earlier, the average person on earth eats nearly twice as much meat each year as did the average person just a few generations ago. While this global figure is important, it contains tremendous disparities in per capita meat consumption particularly between HICs and less developed countries.[4]



Sources: FAO (2021d, 2021e)

Since 1961, global increases in per capita meat production and consumption have been largely driven by the rapid growth and industrialization of poultry and pigs. At the level of per capita production, there has been a five-fold increase in poultry meat, a doubling of pig meat, and a slight decline in beef.

In addition to the strong correlation between rising wealth and rising per capita meat consumption, *there are also important socio-cultural factors that influence consumption*. These include:

- social norms and traditions attached to meat-eating (such as at periodic celebrations);
- religious beliefs (in some cases sanctioning the domination of animals, and in others forbidding the consumption of certain species);
- cultural change via globalization (such as the spread of US pop culture and fast-food chains);
- growing concerns about animal welfare and the unsustainability of meat.

While it is important to take these socio-cultural factors into account in analyzing meatification and prospects for contesting and mitigating it, *it is also necessary to recognize that meat consumption is heavily influenced by powerful actors re-shaping production on a global scale*. TNCs are very active in shaping public attitudes through consumer-oriented marketing campaigns encouraging increased meat consumption, often through straightforward appeals to palate pleasure and sometimes making dubious claims about the superiority of animal proteins. TNCs frequently exert political pressure on government agencies responsible for dietary guidelines (pushing to prioritize the daily intake of animal products) and animal welfare regulations (in some cases, seeking to make investigation and advocacy more difficult). TNCs frequently compliment their marketing campaigns, media outreach, and government lobbying efforts by financing non-governmental organizations (NGOs) and various front groups to indirectly pursue these tasks on their behalf.

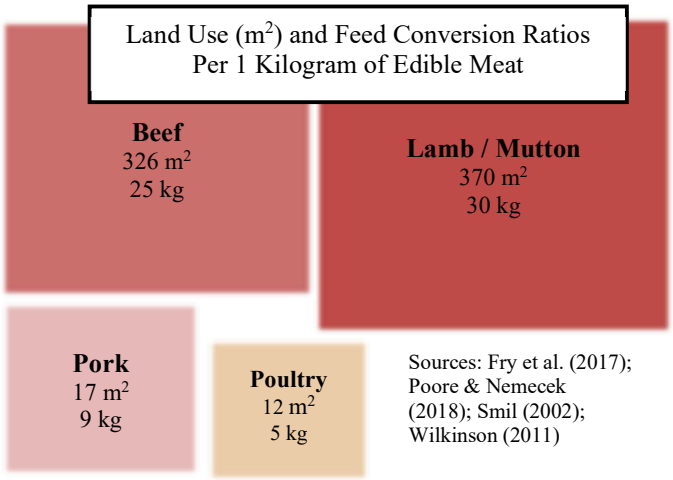
[4] This section is based upon the following sources: Bogueva et al. (2018); Chiles & Fitzgerald (2018); Dagevos & Voordouw (2013); de Bakker & Dagevos (2012); de Boer et al. (2014); FAO (2021e, 2021f); Ipsos MORI (2018); Milford (2019); Perry & Grace (2015); Raphaely & Marinova (2016).

Environmental Impacts

Pasture is the largest anthropogenic land use, followed by *crop production*.[5] The nature of crop production is highly diverse on a spectrum ranging from low-input small farms to resource and pollution intensive industrial monocultures. Industrial monocultures are the predominant source of feed crops and require large volumes of fossil energy (e.g., powering machinery, producing fertilizers and pesticides), freshwater, and other resources, and are a major source of GHG emissions and other pollution loads. The vast extent of pasture and feed crops together make livestock production a central force in the reduction and fragmentation of ecosystems, and hence in biodiversity loss, which also factors in climate change through the long-term decline in carbon sequestration capacity.

> Improvements in feed conversion ratios and the use of other resources in industrial livestock production must be characterized as making these systems *less inefficient* rather than more efficient.

Livestock production is also responsible for the large majority of *total agricultural GHG emissions*. This includes: carbon dioxide (CO_2) emissions from the fossil energy consumed in feed crops and from running livestock operations; methane (CH_4) emissions from the **enteric fermentation** of **ruminants** and the immense aggregations of animal feces; and nitrous oxide (N_2O) emissions, largely from the heavy nitrogen fertilizer use in feed crop production.



Food waste is something that is both a direct environmental harm, adding to landfills and GHG emissions, as well as effectively magnifying the harms associated with production, since it entails additional resource budgets and pollution loads without serving any discernible need. The scale of food waste is gaining increasing visibility, but much attention has focused on the waste generated at the household and retail scales and it is also important to consider **opportunity food loss** and feed conversion ratios. Opportunity food loss signals the inefficiency inherent in livestock production, where much of the nutritional content of feed crops is lost to 'unproductive' metabolic processes as it is cycled through animals to produce meat, milk, and eggs. Opportunity food loss is estimated to be as high as 96% for beef, 90% for pork, and 50% for chicken meat. **Feed conversion ratios** assess the volume of feed inputs to livestock output.

[5] This section is based upon the following sources: Alexander et al. (2017); Alexander et al. (2016); Arcari (2017); Carter (2019); Cassidy et al. (2013); Ceballos et al. (2017); Eisen & Brown (2021); Emery (2018); FAO (2011, 2013, 2017, 2019a); Fry et al. (2017); GRAIN & IATP (2018); Hallström et al. (2015); Harwatt (2019); Hayek (2019); Herrero et al. (2015); IATP & GRAIN (2018); IPCC (2019); Kristiansen et al. (2021); Lazarus et al. (2021); Lee et al. (2019); Manceron et al. (2014); Phelps & Kaplan (2017); Poore & Nemecek (2018); Raphaely & Marinova (2016); Ritchie & Roser (2019a, 2020); Roser & Ritchie (2018); Searchinger et al. (2019); Shepon et al. (2018); Smil (2002); Smith et al. (2013); Springmann et al. (2016); Steinfeld et al. (2006); Swain et al. (2018); Tilman et al. (2017); Treu et al. (2017); van de Kamp et al. (2017); Veeramani et al. (2017); Wada et al. (2011); Weindl et al. (2017); Weis (2013a, 2013b); Wilkinson (2011); Willett et al. (2019); WRI (2020).

Rising meat consumption entails the need to devote more land and resources to production than would be the case with more plant-based diets due to the inherent inefficiency of cycling feed through animals and consequent metabolic losses. *There are tremendous global disparities in the proportions of crop production devoted to human food versus livestock feed*. In the US, which is at the forefront of per capita meat consumption, 67% of all crop production (measured in calories) is devoted to livestock feed and only 27% to food directly consumed by humans. In India, which has a very low level of per capita meat consumption, just 6% of crop production is devoted to livestock feed while 89% is directly consumed by humans. Brazil and China lie in between these two extremes: in Brazil, a similar share of crop production is used for feed (41%) as is directly consumed by humans (45%), while in China more crop production is directly consumed by humans (58%) than is used for livestock feed (33%).

The **ecological hoofprint** is a conceptual framework for understanding the multidimensional burden of industrial livestock production, which must take into account the resource budgets and pollution loads of feed crop production, livestock operations and processing, and the nutritional wastage at their nexus. It helps draw attention to the heightened resource and pollution intensity of meat and livestock products relative to plant-based foods and illuminate why *even those animal products that are deemed to have the lowest environmental impacts still tend to entail greater burdens than the vast majority of plant-based foods*.

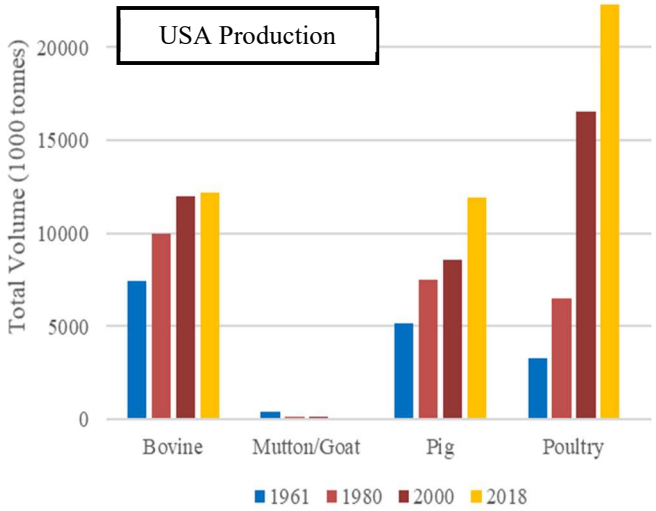
It is well-established that ruminants tend to have the biggest environmental impacts per unit (e.g., GHG emissions, land and water use) regardless of food measurement (e.g., weight, calories, serving), followed by pigs then poultry. As indicated earlier, the global meatification of diets has been heavily powered by pig and chicken production, which each emit less than 10% the global GHG emissions from livestock. While these species may be more efficient than ruminants in land and water use and feed conversion terms, this is better understood as *less inefficient*, and the scale of this growth still significantly contributes to a range of environmental harms as well as fast-rising animal populations which are mired in the worst welfare conditions.

Any prospect of mitigating the extent of climate change demands urgent changes in agro-food systems and most of all dramatic reductions in the scale of global livestock production and consumption. If the trajectory of meatification continues, livestock production alone entails levels of GHG emissions that cannot be reconciled with agricultural targets for keeping warming below 1.5ºC. Conversely, on a hopeful note, if livestock production were drastically reduced, and nutrition derived primarily from plant-based foods, this would greatly reduce the world's GHG emissions and free up large areas of land for ecological restoration and enhanced carbon sequestration.

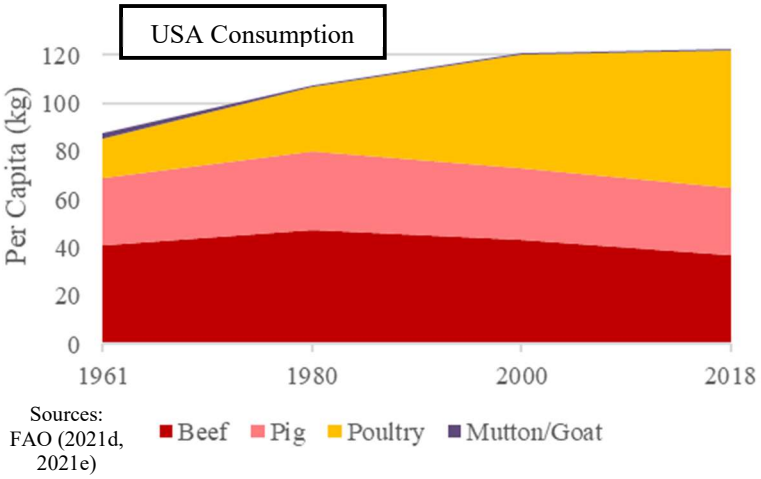
United States

The US has been at the forefront of the global industrialization of livestock production and rising per capita meat consumption.[6] Between 1961 and 2018, the US human population rose by 74% while the total volume of meat consumed grew almost twice as fast, growing by 145%. This involved a tripling of the population of the big five livestock species, an even bigger increase in the population of animals slaughtered annually, and large increases in the average yields of flesh per animal.

In 1961, US meat production was overwhelmingly centered on cattle and pigs. By 2018, poultry was by far the biggest source of meat, and with just over 4% of the world's population, the US now produces around 17% of the world's poultry meat. While cattle has declined as a relative share of total meat production in the US, beef remains the most lucrative animal species produced for meat.



Sources: FAO (2021d, 2021e); World Bank (2021)



Sources: FAO (2021d, 2021e)

The US tops the world in per capita meat consumption, which rose from 101 kg in 1961 to 145 kg in 2018. The steady increase in US per capita meat consumption has been driven by the tremendous surge in poultry meat production noted above. From 1961 to 2018, the average American consumed slightly less pork and beef on an annual basis but ate nearly 40 kg more poultry meat.

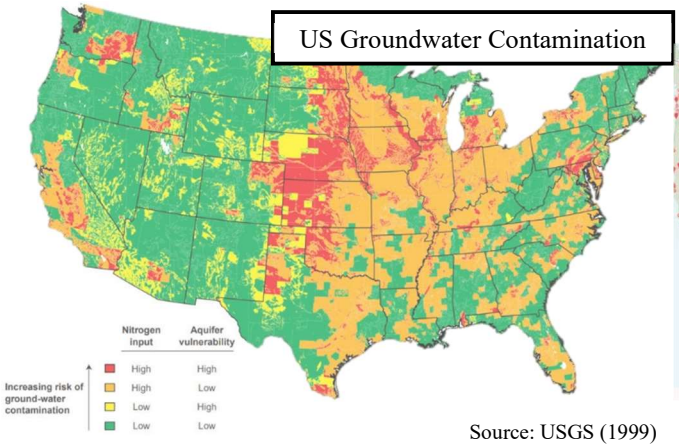
US primacy in per capita meat production and consumption is the principal reason why the average American commands far more arable land, freshwater, and other agricultural resources than the average person on earth. The majority of cultivated land in the US is devoted to primary feed crops, and the US produced 16% of the total global volume of feed crops in 2017.

[6] This section is based upon the following sources: (Fehrenbach et al. (2016); FAO (2021a, 2021b, 2021e, 2021f); Franck et al. (2013); Harwatt et al. (2017); Hayek (2019); Hendrickson et al. (2020); Hribar (2010); Kappeler et al. (2013); Leiserowitz (2020); MarketLine (2019c); Simon (2013); Tyson Foods (2021); USDA ERS (2021); EPA (2019); US NCHS (2015); Wang et al. (2018); Winders & Nibert (2004); World Bank (2021); WITS (2019b).

In 2019 the US Environmental Protection Agency (EPA) estimated that the agricultural sector was directly responsible for about 10% (656 million tonnes CO_2 equivalent) of the country's total GHG emissions, of which nearly 40% was attributed to livestock production. However, this estimate does not include the historical land use change associated with livestock (and diminished carbon sequestration capacity), the energy used in livestock processing, or the transportation of inputs and animals throughout the production process.

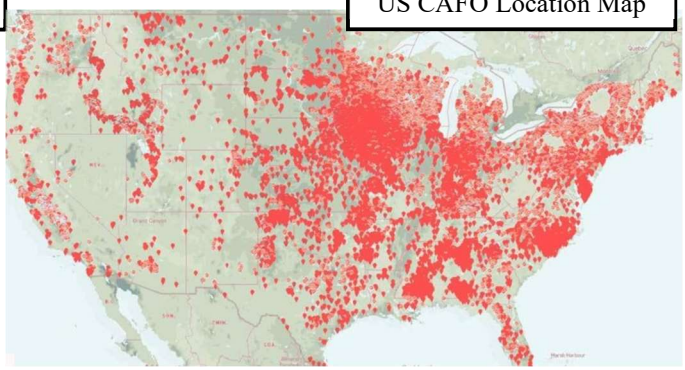
Because of the large amount of land devoted to feed together with the opportunity food loss from feed conversion inefficiencies, it is estimated that growing beans instead of beef to generate a comparable level of nutrition would free up 42% of current US agricultural land for other uses. The US EPA also identifies livestock production as the leading source of water pollution in the US, due to the fertilizers and pesticides used in feed crop production combined with the seepage manure 'lagoons' on **concentrated animal feeding operations** (CAFOs). This pollution burden threatens ecosystem health in rivers, lakes, and ocean coasts, as indicated in the maps below.

US Groundwater Contamination



Source: USGS (1999)

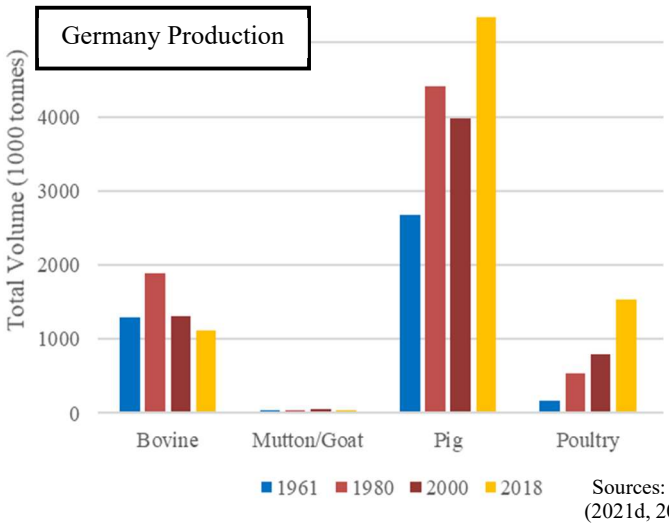
US CAFO Location Map



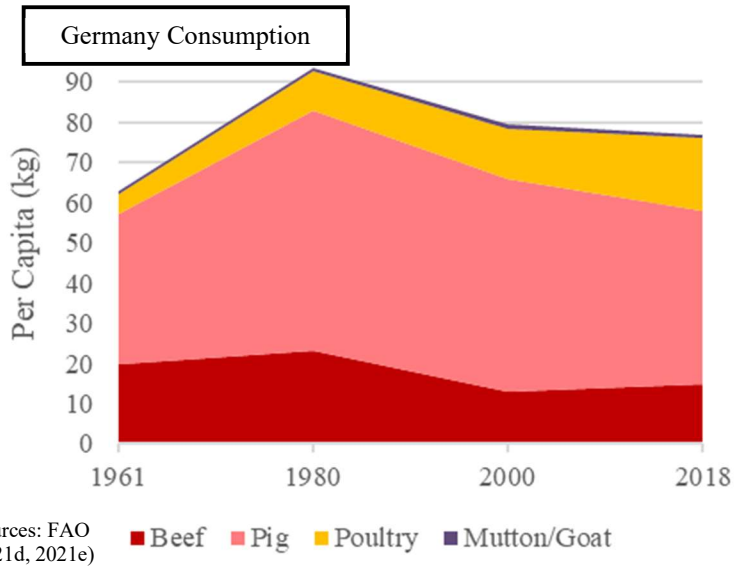
Source: Project CounterGlow (2020)

Germany

Germany is Europe's second most populous country, and it is a large livestock producer with high per capita meat consumption.[7] From 1961 to 2018, Germany's human population grew by 12% and its big five livestock population increased by 47%. Pigs have long been by far the biggest source of meat production and consumption in Germany, and the population of pigs slaughtered annually nearly doubling from 1961 to 2018. Poultry production has also increased significantly during this time, with 4.5 times more animals slaughtered on an annual basis and the average bird yielding twice as much flesh.



Sources: FAO (2021d, 2021e); World Bank (2021)



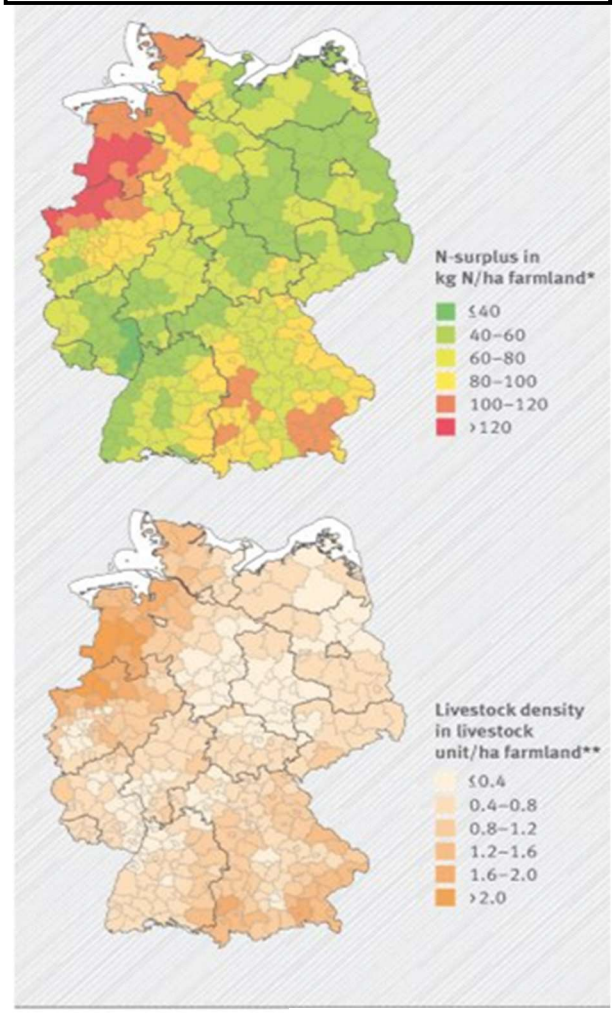
Sources: FAO (2021d, 2021e)

This rapid increase in poultry production is due to factors such as lower costs and health recommendation about the benefits of white meat relative to red meat. In 2018, the annual per capita availability of animal flesh was 79 kg.

Germany's relatively high per capita levels of meat consumption are an important aspect of its outsized agricultural- and diet-related environmental harms. In 2015, Germany emitted 67 million tonnes of GHG emissions (CO_2 equivalent), and livestock production is identified as the second-largest source of emissions after electricity generation. Part of this relates to the emissions from ruminants, animal manure, and industrial livestock operations and processing facilities, and another part relates to the emissions associated with feed crop production. Agriculture occupies over half of the total land area in Germany, and feed crops account for over one-third of all cropland. Further, Germany is a significant importer of feed crops from the US and southern South America, and the emissions associated with the production and movement of these crops do not register in this accounting.

[7] This section is based upon the following sources: Collaborative Working Group on Sustainable Animal Production (2019); Feedback Global (2020); FAO (2021d); German Environment Agency (2018); German Ministry of Food (2007); German Nutrition Society (2012); Hallmann et al. (2017); MarketLine (2019b); Tönnies Group (2021); World Bank (2021); WITS (2019a); Xue et al. (2019).

Germany livestock density and nitrogen surplus



* Mean of the years 2012–2014
** 2013

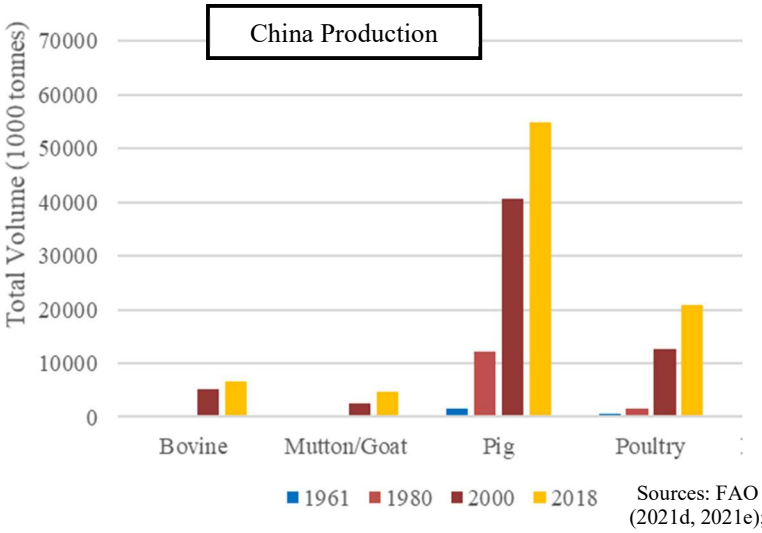
Source: German Environment Agency (2018)

Water pollution is another significant environmental harm from livestock production in Germany, stemming from the fertilizer and chemical intensity of feed crop production as well as the large volumes of manure generated by livestock animals. Nutrient loading is particularly problematic in north western Germany, where livestock density is especially high (as indicated in the accompanying maps) and large volumes of liquid manure are regularly spread on crop fields. This leads to widespread problems of algae blooms and eutrophication in lakes and coastal areas. The heavy use of pesticides also adversely affects biodiversity, including the decline of many wild animal species. The threats to biodiversity from the combination of pesticides and habitat loss were dramatically illustrated in a long-term survey showing massive declines in insect biomass in Germany, even in national parks, which drew a great deal of global attention in 2017.

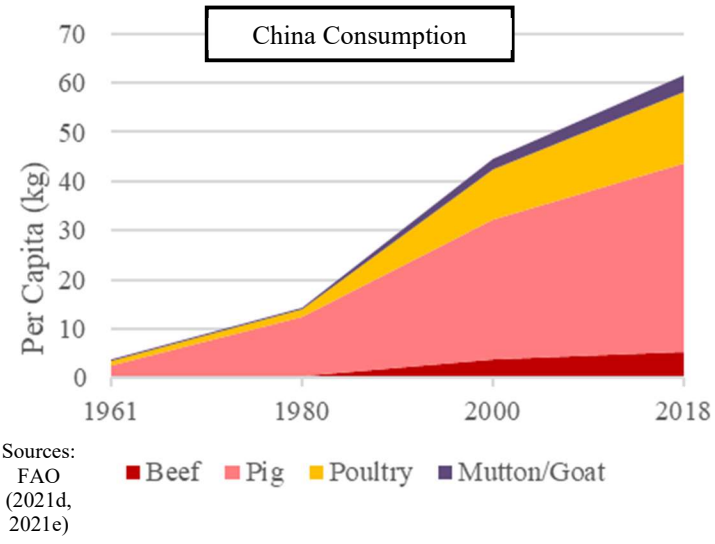
China

In the early 1980s, China's livestock industry began a dramatic transformation growing and industrializing at a breakneck pace. In less than half a century, China moved from having levels of meat production and consumption that were far below the world's average to becoming the world's largest meat producer by total volume.[8] Between 1961 and 2018, China's human population more than doubled while the total population of its big five livestock species increased nearly 8-fold and the population of animals slaughtered annually increased 22-fold. China is now home to roughly half the world's pigs, and the average pig yielded 79% more flesh in 2018 than in 1961.

China currently produces nearly *half* of the total global volume of pig meat. Livestock production in China is bifurcated between small-scale production at the village scale, and fast-growing industrial operations connected to 'dragon-head' enterprises, the most dramatic expression of which is the recent development of multi-story pig enclosures euphemistically dubbed 'hog hotels.'



Sources: FAO (2021d, 2021e); World Bank (2021)



Sources: FAO (2021d, 2021e)

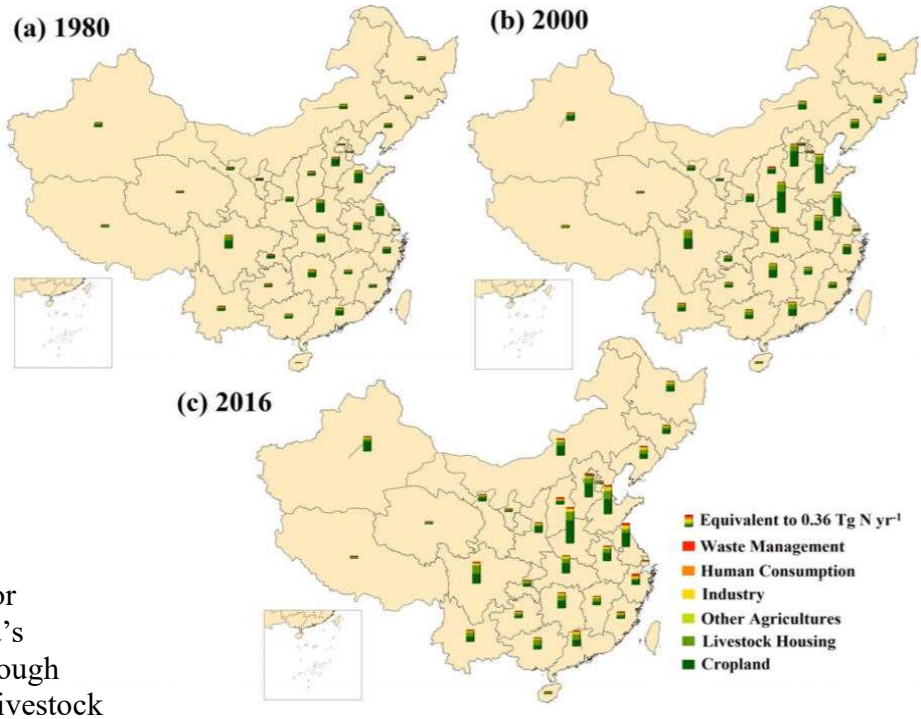
Between 1961 to 2018, the per capita levels of meat available for consumption in China increased 16-fold, from 4 kg to 62 kg, with pig meat roughly two-thirds the total in 2018.

The Chinese state actively encouraged rising meat consumption for decades, led by pigs. This was rooted in strong cultural attachments to pig meat, reflected in overlapping terminology for pig, pork, and meat in the mandarin language, though this arose over centuries when pig meat consumption was rare are associated with periodic events. China's food culture in its rapidly growing cities has also been influenced by the proliferation of fast-food restaurants and supermarkets in recent decades. Surveys indicate that many urban consumers prefer to purchase processed meat from industrial producers at supermarkets because of convenience and because they deem it safer than meat from **wet markets**.

[8] This section is based upon the following sources: Al-ali et al. (2018); Bai et al. (2018); Bingsheng (2002); Bouwman et al. (1997); de Barcellos et al. (2013); Du et al. (2018); FAO (2021c, 2021d); Fu et al. (2020); Mannion (2018); MarketLine (2019a); Robinson et al. (2011); Schneider (2017); Schneider & Sharma (2014); Wang et al. (2018); World Bank (2021); Xu et al. (2019); Yue et al. (2017).

As the 21st century 'workshop of the world,' China overtook the US in the 2010s as the country with the biggest total annual GHG emissions, although its per capita GHG emissions remain well below those of the US and some other industrialized countries. The biggest sources of GHG emissions in China are its electricity grid (heavily coal) and manufacturing sector, while agriculture is responsible for just under one-fifth of China's total GHG emissions. Livestock production is responsible for close to two-fifths of China's agricultural emissions, although as with Germany, its total livestock emissions are undercounted given the emissions associated with the production and importation of feed crops.

Rising Ammonia Emissions in China

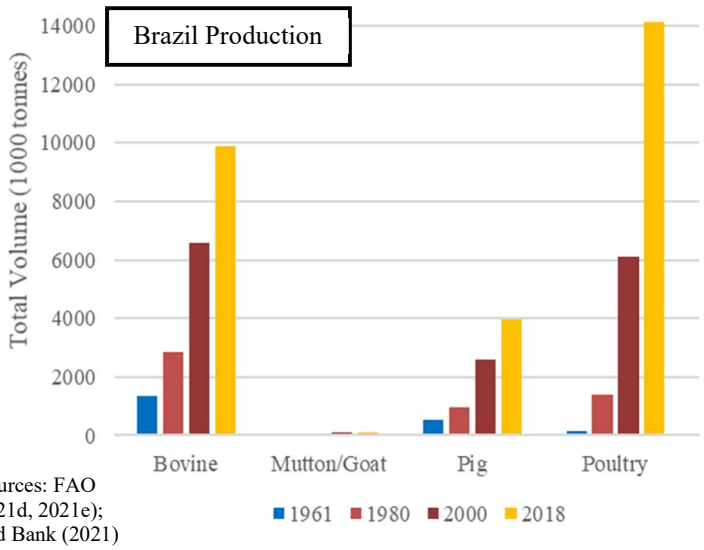


Source: Fu et al. (2020)

Chinese cities suffer from the worst average air quality in the world. Coal powered plants and factories are the biggest source of China's air quality problems, but livestock production makes conditions worse. Livestock production is responsible for roughly two-thirds of China's rising ammonia emissions (illustrated in the accompanying maps), through the combination of manure and nitrogen fertilizer used on feed crops, and this exacerbates the health problems associated with **particulate matter**.

Brazil

Brazil ranks among the world's most agricultural productive countries and runs a large agro-trade surplus. Historically, Brazil's agro-exports focused on tropical commodities like sugar and coffee, but its contemporary agro-exports are extremely diversified, including its position as one of the leading producers and exporters of meat and livestock feed. [9] In 2018, Brazil was the world's second-largest producer of beef and chicken meat, largest exported of beef, and second largest exporter of soybeans.

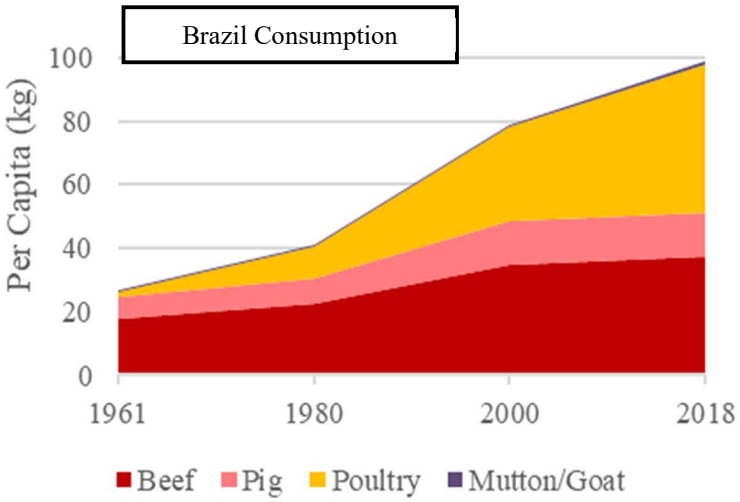


Sources: FAO (2021d, 2021e); World Bank (2021)

From 1961 to 2018, Brazil's human population nearly tripled while the population of the big five livestock species increased almost 8-fold and the population of animals slaughtered annually soared nearly 40-fold, driven by the soaring production of chickens. The average yield of flesh per animal increased across all species, led by poultry which increased 137% during this time.

In 2018, Brazil supplied 20% of global beef exports (predominately to China), and nearly 40% of global poultry exports. In addition to rising meat exports, Brazil is the world's largest exporter of soybeans, most of which flow to China, where they constitute a crucial part of industrial livestock production.

From 1961 to 2018, the amount of meat available for consumption in Brazil nearly tripled. The exploding scale of poultry production has been at the forefront of both rising meat consumption and exports, while beef and pork have risen more slowly. Per capita meat consumption in Brazil now ranks among the highest in the world and has even surpassed the extremely high levels of many HICs.



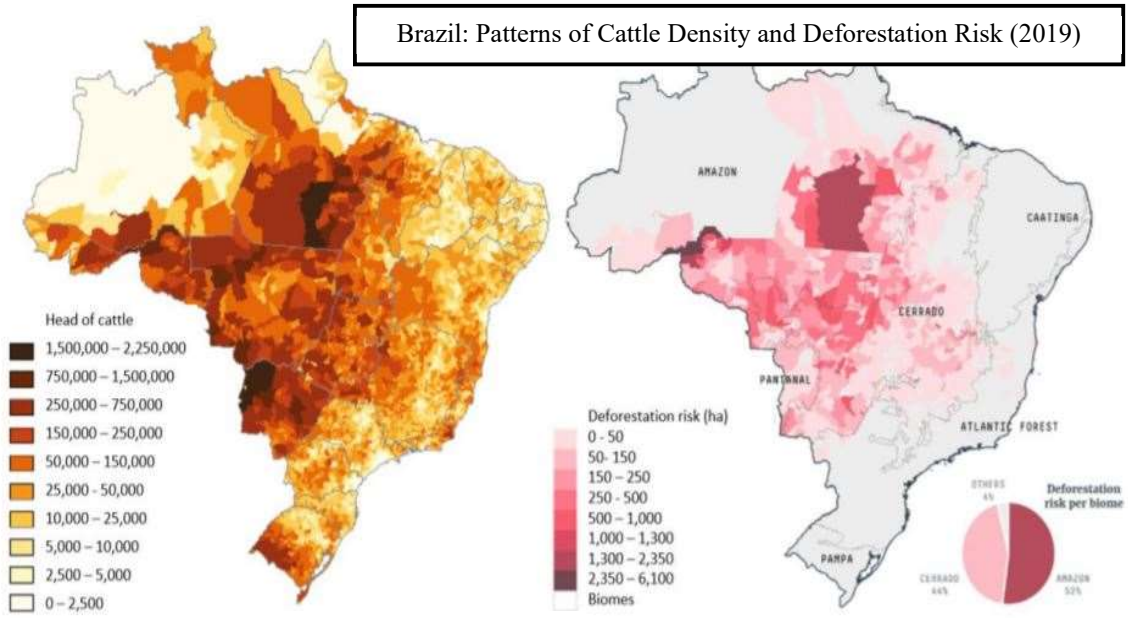
Sources: FAO (2021d, 2021e)

[9] This section is based upon the following sources: Brazilian Trade and Investment Promotion Agency & Brazilian Beef Exporters Association (2016); da Silva Gomes & Mariana (2013); FAO (2021c, 2021d, 2021e, 2021f); Happer & Wellesley (2019); Instituto Escolhas (2020); JBS Foods (2019, 2021); Kuepper et al. (2020); Nepstad et al. (2014); Sharma (2014); Sharma & Schlesinger (2017); Timperley (2018); World Bank (2021).

After the US and China, Brazil is now the third largest meat producer in the world. It also ranks among the global leaders in livestock-related GHG emissions. In 2017, Brazil was responsible for 18% of the total global GHG emissions (CO_2 equivalent) associated with the production of beef, pig, and chicken meat. Agriculture and pasture are Brazil's leading sources of GHG emissions (34%), with their role in the destruction of the Amazonian rainforest at the forefront of this. The maps below indicate the expansion of cattle ranching westwards and northwards into Amazonia and its spatial correlation to ongoing risks of deforestation.

The dynamics of Amazonian deforestation are complex and relate to a range of factors including the assertion of territorial dominance by the Brazilian state, land speculation by elites, encouraged smallholder migration, sub-surface mineral extraction, and hydro-electric dam projects. However, cattle have consistently been a central part of the story, as low-density cattle pastures occupy by far the most area of all deforested land in Amazonia and, in addition to the earnings from ranching this has helped to mark property rights and enable (distant elites) to assert control over vast spaces. In recent decades, high-input soybean monocultures—used principally for livestock feed—have also expanded upon deforested land.

Brazil: Patterns of Cattle Density and Deforestation Risk (2019)



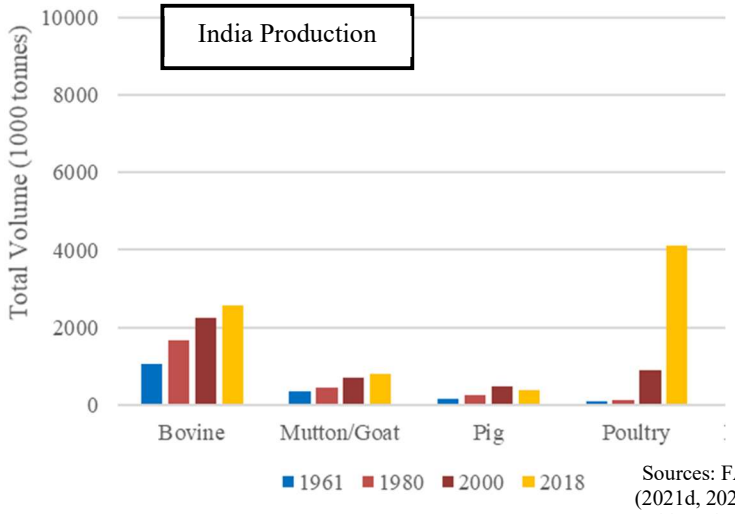
Source: Kuepper et al. (2020)

As the massive rainforests of Amazonia (a significant **carbon reservoir**) are reduced, there is a doubly negative dynamic for the carbon cycle: the initial burst of CO_2 into the atmosphere as the forest-based carbon is cleared and burned, and the long-term reduction in carbon sequestration capacity as there is less forest to draw down CO_2 from the atmosphere. The atmospheric implication is made worse still by the CH_4 emissions from cattle, which are a major source of the total GHG emissions from Brazilian agriculture.

India

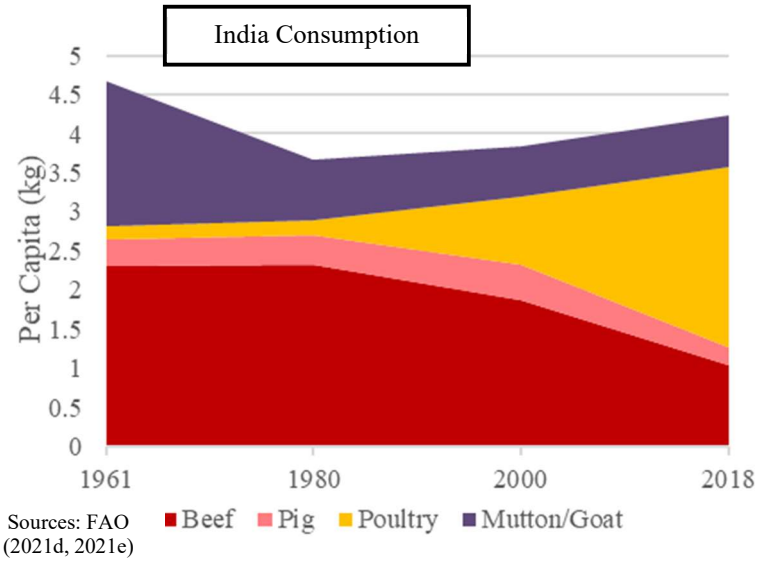
India is sometimes assumed to be a largely vegetarian nation because of the sacredness of cows in Hinduism, the country's biggest religion.[10] There is some degree of truth to this, as per capita meat production and consumption in India are far below world averages and have risen much slower than in most other parts of the world. It is also common for meat-eaters to sometimes describe their diets as 'non-vegetarian.'

However, from 1961 to 2018, India's human population and the total population of the big five livestock species both roughly tripled. However, the population of animals slaughtered annually grew nearly 20-fold during this time, due mainly to the surge in chicken production. Livestock yields have also risen, although more slowly than in many parts of the world, with the average poultry bird yielding 66% more flesh in 2018 than in 1961.



Sources: FAO (2021d, 2021e); World Bank (2021)

Both cattle and buffalo are prized for their milk, labour power, and manure (which has value both as fertilizer and fuel), with one big difference: whereas the slaughter of cows is illegal in most Indian states, the production of buffalo meat has risen such that India was the world's fourth largest exporter of bovine meat in 2020, which is largely exported to Southeast Asia. In 2017, buffalo constituted 97% of India's meat exports. While most chickens were slaughtered around households, in wet markets, or by small-scale butchers until quite recently, the increasing industrialization of chicken slaughter and processing is rapidly transforming how people encounter chicken meat, especially in fast-growing cities where supermarkets are also expanding.

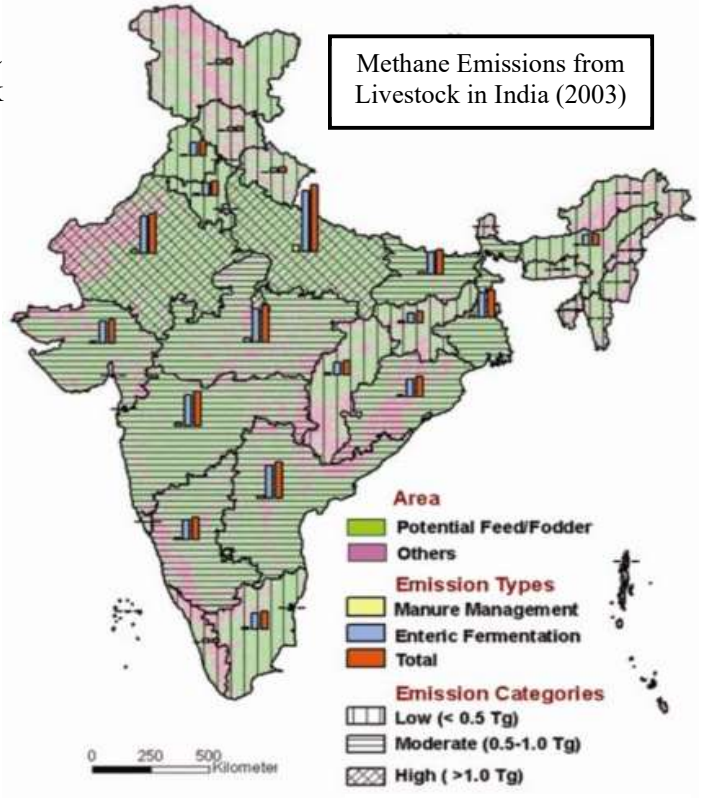


Sources: FAO (2021d, 2021e)

The annual per capita meat available for consumption in India was fairly stable from 1961 to 2018, rising less than 0.5 kg (from 3.7 kg to 4.1 kg). While there is not a strong cultural attachment to meat consumption in India, it is notable that India's national nutritional guides recommend a level of consumption that is roughly double the per capita quantity of meat available for consumption, which would require a huge increase in production.

[10] This section is based upon the following sources: Bhushi (2017); Chemnitz et al. (2014); Chhabra et al. (2009); Filippini & Srinivasan (2019); FAO (2021c, 2021e, 2021f, 2021h); Jakobsen & Hansen (2019); Khadse (2016); Kochewad (2017); Kumar et al. (2018); Mehta (2008); Salunkhe & Deshmush (2012); Sathyamala (2019); Srinivasan & Rao (2015); Vetter et al. (2017); World Bank (2021); Yadav & Kumar (2006).

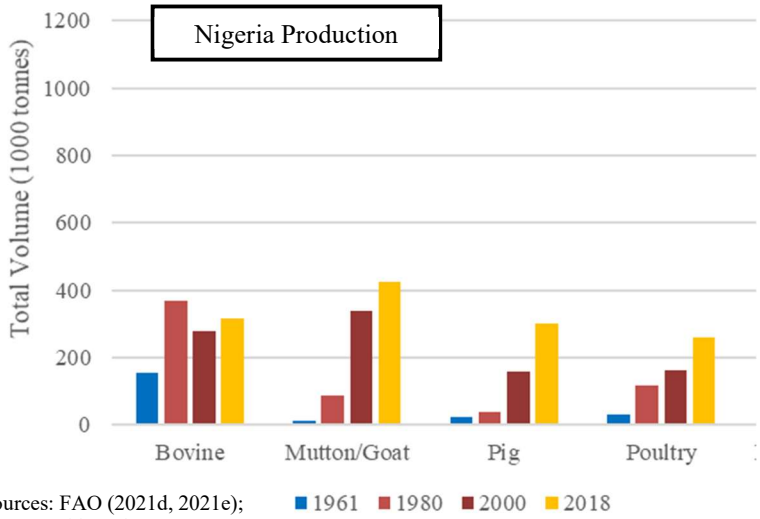
Although meat consumption in India is very low by world standards, livestock production nevertheless makes a major contribution to environmental harms, especially involving cattle, buffalo, and goats. India has the world's largest population of bovine animals, as well as a large goat population, and these animals command a significant share of the country's arable land, which reduces the space for natural ecosystems. Agriculture is responsible for about 18% of India's total GHG emissions, and the CH_4 emissions from ruminant animals (highlighted in the accompanying map), constitute the single biggest component of this atmospheric impact.



Source: Chhabra et al. (2009)

Nigeria

At the point of Nigeria's independence in 1960, agriculture was by far the largest livelihood and economic sector in the country.[11] However, the importance of agriculture to the national economy began to quickly decline in the 1960s as the Nigerian state focused heavily on the exploitation of newly discovered oil and gas resources, resulting in fast-rising food import dependence.

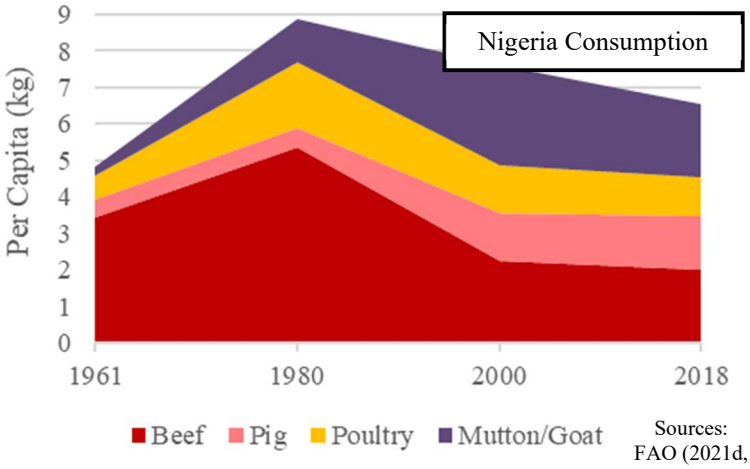


Sources: FAO (2021d, 2021e); World Bank (2021)

Between 1961 and 2018, Nigeria's human population quadrupled, and it is the most populous country in Africa and the seventh most populous in the world. Although the population of the big five livestock species in Nigeria tripled between 1961 and 2018, this was still slower than human population growth (unique among the case studies here) and per capita meat consumption remains very low by world standards.

Livestock production in Nigeria has long centered upon cattle, goats, and sheep, but the production of poultry and pigs has expanded since independence (pigs mostly in the south where Muslims comprise a smaller share of the population), and today production is spread relatively equally among the big five livestock species. While Nigerian poultry and pig production are generally far less industrialized than in many other parts of the world, it is estimated that intensive and semi-intensive systems now produce just over half of the total number of poultry birds in the country. In spite of this growth, poultry meat continues to cost more than comparable products produced in more developed countries. One factor in this is the government's restriction on the importation of meat products into the country, which has limited the presence of foreign-based TNCs and the availability of cheap, industrially produced meat.

The per capita meat availability in Nigeria has changed very little since 1961, rising slightly in the 1960s and 1970s and slightly declining since, as human population growth has outpaced the growth of livestock production. As in China, India, and many other countries, the globalization of western food culture is strongest in Nigerian cities and has influenced the cultural desirability of meat-eating. Modern supermarkets are growing in more affluent urban areas in Nigeria, but fast-food TNCs as yet have only a limited presence.



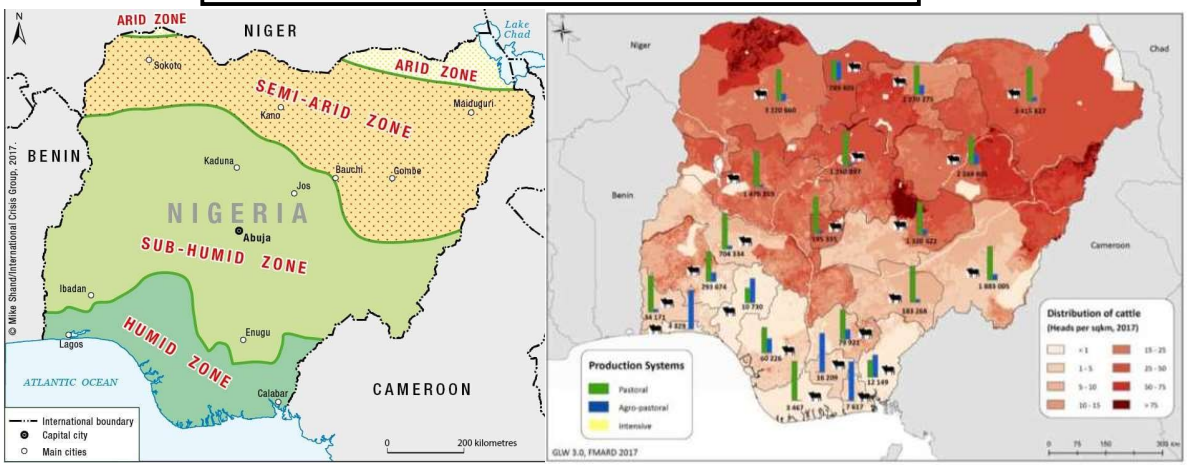
Sources: FAO (2021d, 2021e)

[11] This section is based upon the following sources: Adetenji & Rauf (2012); Ajadi (2018); Bonnet et al. (2011); FAO (2005, 2019b, 2021c, 2021e, 2021f); Gavrilova (2020); Igbokwe (2018); ICG (2017); Lenshie et al. (2020); NatnudO Group (2021); Ogunleye et al. (2016); Olagunju (2015); Osazuwa-Peters (2021); World Bank (2021).

Extensive pastoralism accounts for roughly half of all livestock operations in Nigeria, with 90% of the cattle population and two-thirds of the sheep and goat population in the northern region where arid and semi-arid ecozones are pervasive. The spatial correlation between cattle density and drylands in Nigeria is illustrated in the provided maps. Historically, herders in the northern part of the country tended to move livestock animals over large areas following seasonal rains, but colonialism and rising private property regimes are significantly reducing migratory corridors. Today, climate change is further complicating extensive herding, making arid and semi-arid lands hotter, drier, less productive, and more prone to soil erosion and **desertification**, reducing available forage for grazing, agricultural yields where crops are planted, ground- and surface-water resources, and habitat for wild animals. As a result, the future of this region hinges on the urgency of global scale action to mitigate the extent of warming.

At the same time as global dynamics are inescapable, the environmental pressure associated with climate change and desertification must also be understood in the context of accelerating deforestation, rising stock densities, and reduced long-distance movement of herded animals in Nigeria. In just two decades, from 1990 to 2010, Nigeria's primary forest cover was cut in half, with **overgrazing** of herded livestock, over-cultivation, and harvesting of wood for fuel deemed to be the key driving factors. As well as being *exacerbated by* the hotter and drier conditions caused by climate change, desertification also serves to amplify warming through the reduction of carbon stored in soils and vegetation.

Nigeria's Primary Ecozones and Cattle Population Density



Source: ICG (2017) Source: Igbokwe (2018)

The Re-Meatification of Diets

Although most global assessments of agriculture and food production assume that livestock production and consumption will continue rising, there are many activists, scholars, non-governmental organizations, consumers, and enterprises contesting this trajectory in various ways.[12] One important dimension of this challenge is to promote the progressive substitution of plant-meat for animal flesh, or what can be conceived as *the re-meatification of diets, which has the potential to rapidly reduce the GHG emissions and other environmental harms associated with industrial livestock production*.

> Given how entrenched meat-based food habits and palate pleasure are in many places, a *re-meatification of diets may be our best bet to quickly reverse the trajectory of meatification and its associated environmental harms*.

Re-meatification responds to the urgent need for radical dietary transitions without compelling people to radically re-think the way they eat and cook. This starts from a recognition of the barriers to change presented by such things as: cravings and palate pleasure; the cultural values attached to animal flesh; and its place within established food preparation and cooking skills, eating habits, and retail environments like fast-food restaurants. *By enhancing the ease of substitution, plant-meat products have both a disruptive and non-disruptive character.*

Twitter (2021).

As this report has stressed, patterns of meatification are highly uneven on a global scale. The growth of plant-meat production and consumption reflects this disparity, with HICs and some UMICs at the forefront of product development, mass-marketing, and consumer adoption.

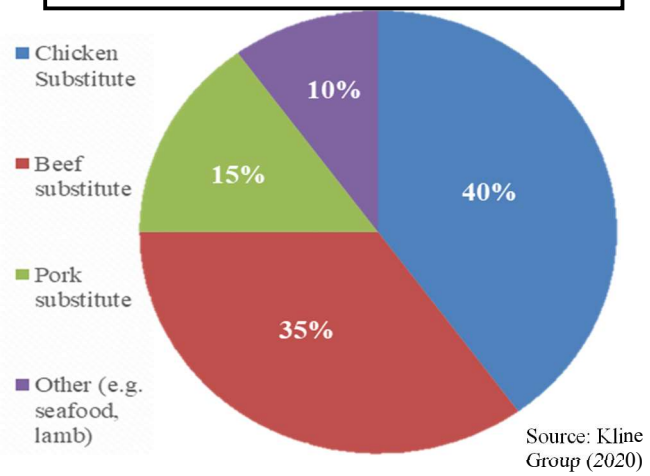
[12] This section is based upon the following sources: Aleksandrowicz (2016); Bajželj et al. (2014); Cederberg et al. (2013); Gabbatiss (2020); Godfray et al. (2018); Happer & Wellesley (2019); Harwatt (2019); Harwatt et al. (2017); Hayek (2019); Hedenus et al. (2014); Hertwich et al. (2010); Popp et al. (2010); Raphaely & Marinova (2016); Ray et al. (2013); Rivera-Ferre (2009); Smith et al. (2013); Twine (2018); Willett et al. (2019).

Plant-Meat Production

Modern plant-meat products are comprised of varying combinations of pulses, grains, nuts, vegetables, and fungi combined with spices, stabilizing agents, and flavour enhancers, which are processed into forms designed to mimic the fibrous structure of animal flesh.[13] Conceptions of plant-meat are not entirely novel, as the first recorded product dates back to 14th century China. However, while some new plant-meat products reflect older traditions, many do not. The number of plant-meat products launched in global markets has grown dramatically since the 2000s, driven by a combination of rising consumer demand and surging innovation that is coming from both specialized plant-based start-ups and large TNCs that focus on livestock processing and processed foods.

There is no definitive definition for what constitutes plant-meat, and in general products can be seen to occupy different places on a spectrum involving varying degrees of processing and emulation of animal flesh. On one side are 'ultra-processed' products designed to mimic the taste and texture of animal flesh as closely as possible, which often involves novel ingredients (e.g., Impossible Food's soy leghemoglobin, a vegetable-based iron-rich protein that simulates meaty taste and bloody aesthetic) and/or sophisticated technological processes (e.g., twin-screw extrusion, shear cell texturization, 3D printing). On the other side are much simpler products made by individuals, micro-enterprises, and smaller-scale institutions that tend to be geared towards localized consumption and sometimes bear less resemblance to animal flesh.

Global Market Share of Plant-Meat Production
Retail Sales by Type (2019)



Source: Kline Group (2020)

In 2020, Europe had by far the largest share of the global plant-meat market (52%), followed by North America (27%) and Asia Pacific (12%). Soybeans are the most common plant protein used in modern plant-meat products on a world scale, followed by wheat, peas, rice, and a variety of vegetables. In 2019, chicken and beef substitutes comprised roughly three-quarters of all plant-meat products based on share of global retail sales. However, the greater household character of plant-meat production in Asia means that assessments solely focusing on market sales underrepresents its importance in consumption there.

The growing scale of heavily processed and closer-to-flesh plant-meat products can be easily plugged into established energy-intensive distribution and logistics systems that are most developed in HICs and UMICs. In lower income countries, plant-meat production and retail availability are increasing, and rapid growth could help steer people away from the animal-heavy dietary transitions that have previously been associated with development.

[13] This section is based upon the following sources: Adams (2018); Boukid (2021); Dagevos (2016); Gaan (2021); Grahl et al. (2018); Gunther (2013); Kline Group (2020); McClements & Grossmann (2021); Mintel (2018, 2020); Morris (2018); Nierenberg (2020); Olayanju (2019); Shurtleff & Aoyagi (2014).

Plant-Meat Consumption

The development of plant-meat products explicitly targets the palate preferences, cultural affinities, and food preparation and cooking skills in meat-heavy cuisines.[14] The most common highly processed plant-meats are burgers, sausages, chicken-like tenders or nuggets, and cold cuts, which points to the fact that product development so far has been largely positioned in relation to mainstream food cultures in HICs. This is an obvious and necessary starting point, since per capita meat consumption is the highest in HICs, and because of the influential role of western food cultures affecting dietary aspirations around the world, such as through the spread of fast-food chains, processed foods, and associated marketing.

Some consumer research suggests that while vegetarians and vegan comprise significant parts of the intended and actual markets for plant-meat, omnivores still consume the majority of all plant-meat produced. The role of omnivores in rising demand for plant-meat highlights the increasing comparability of tastes, textures, and cooking practices, and suggests that plant-meat consumption will increase across all dietary typologies, particularly as technological innovation continues to lower costs and increase the available range and quality of plant-meat products.

A Snapshot of Plant-Meat Products on a Supermarket Shelf in Western Europe

Source: Tischbeinahe (2021)

Assessments of plant-meat consumption show that cultural differences significantly affect the potential for widespread substitution. For instance, researchers have found that individuals in China and India—countries with long histories of non-industrially produced plant-based substitutes—tend to be much more accepting of plant-meat compared to individuals in the US, and much more individuals willing to purchase it.

Ultimately, if plant-meat products merely get entrenched in parallel niche markets for practicing vegetarians and vegans while being sporadically consumed by omnivores who maintain meat-heavy diets, it will do little to affect the unsustainable, inequitable, and violent course of agro-food systems. For re-meatification to occur, continuing technological innovation and greater emulation of the tastes and textures of animal flesh are not sufficient. Rather, plant-meat promotion must be tailored to different food cultures and make the benefits of progressive or complete substitution clear—a central part of which is to make the environmental harms of livestock production and animal flesh consumption explicit. While this is partly a matter of marketing, the rising presence of TNCs engaged in both animal and plant-meat products obviously impedes such prospects and places greater onus on those companies that specialize in plant-meats. It also implies that environmental and animal advocates have roles to play in making the case for plant-meat substitution in accessible and compelling terms.

[14] This section is based upon the following sources: Bryant et al. (2019); Clark & Bogdan (2019); Dagevos (2016); Euromonitor International (2020); Gray (2020); Hartmann & Siegrist (2017); Kumar et al. (2017); Lacroix & Gifford (2020); Lai et al. (2020); Raphaely & Marinova (2016); Siegrist & Hartmann (2019); Slade (2018); Twine (2018); Twitter (2021).

Environmental Impacts

There is overwhelming scientific evidence that plant-based diets significantly reduce environmental harms relative to diets heavy in animal products.[15] *Plant-based diets entail much lower GHG emissions and much less land, water, fertilizers, and pesticides because they supplant the immense opportunity food losses that are associated with funneling feed crops through animals and the resource and pollution intensity of livestock operations*. Opportunity food losses are so great that a global-scale shift to plant-based diets could reduce the land needed for agriculture from 4 to 1 billion hectares. This would greatly enhance the prospects for ecological restoration, particularly for large-scale reforestation, benefitting both biodiversity conservation and climate change mitigation.

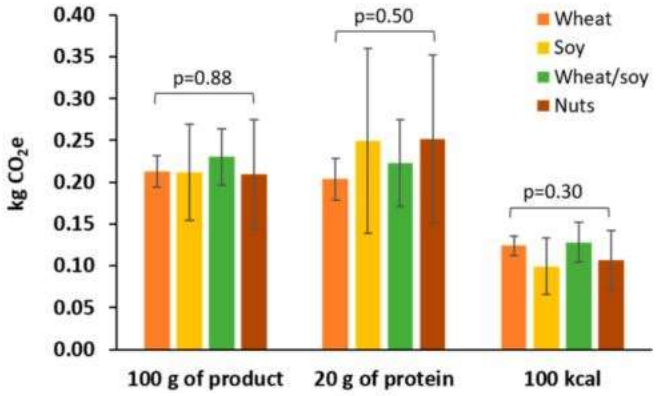
Land Use (m^2) Per 1 Kilogram of Edible Product

Source: Poore & Nemecek (2018).

Many studies seek to demonstrate the differences in how sustainable foods are by comparing whole diets. While some variability of environmental impacts *within* dietary typologies is expected (e.g., a vegetarian diet will contribute significantly more GHG emissions if it contains large amounts of dairy products), diets without any animal products invariably perform the best across all measures and across different countries.

Plant-meats have very similar environmental impacts to the legumes, oilseeds, grains, and vegetables they are mostly comprised of, except that they require more energy during the processing, distribution, and storage (e.g., refrigeration) phases. There are no significant differences between the contributions to GHG emissions and land and water use between common types of plant-meats, regardless of whether they are measured in terms of product weight, quantity of protein, or caloric volume (though there is some evidence that mycoprotein-based plant-meat may have slightly higher environmental impacts than other plant-meats).

GHG Emissions by Main Ingredient of Plant-Meat

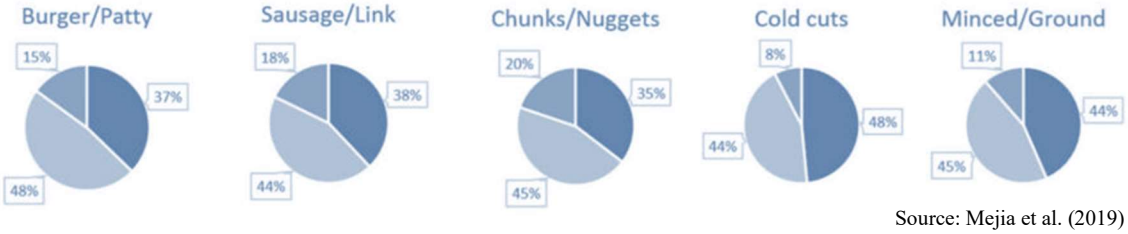


Source: Fresán et al. (2019)

[15] This section is based upon the following sources: Bajželj et al. (2014); Bonnet et al. (2018); Cederberg et al. (2013); Dettling et al. (2016); Fresán et al. (2019); Godfray et al. (2010); Harwatt et al. (2017); Hedenus et al. (2014); Hertwich et al. (2010); Keoleian & Heller (2018); Kim et al. (2020); Mejia et al. (2019); Poore & Nemecek (2018); Popp et al. (2010); Raphaely & Marinova (2016); Ray et al. (2013); Ritchie (2021); Rosi et al. (2017); Smetana et al. (2015); Springmann et al. (2018); Willett et al. (2019).

Lifecycle assessments have found that an average kilogram of plant-meat entails just over 2 kg of CO_2 equivalent, nearly half of which (45%) results from the manufacturing processes (mainly energy to run the machines and facilities), with some small differences between various forms of plant-meat. This means that there is tremendous scope to further reduce the environmental impacts of plant-meat production the more electricity generation is derived from clean energy sources like wind and solar.

GHG Emissions by Stage of Production Across Plant-Meat Forms



Source: Mejia et al. (2019)

TNCs and allied scientists involved in livestock production and processing are pursuing a wide range of technological innovations geared to improving efficiency and reducing relative pollution loads. However, it is abundantly clear that the multidimensional environmental harms (and interspecies violence) associated with livestock production can be mitigated to a far greater extent through dietary transitions towards greater reliance on plant-based nutrition. Plant-meats have a crucial part to play accelerating such dietary change, and more outreach is needed to widen and deepen recognition of this environmental case; in essence, to help more people understand and be capable of explaining the importance of re-meatification to others.

United States

Although plant-meat consumption is rising quickly in the US, at the same time total livestock production is continuing to grow through a combination of rising domestic consumption and exports.[16] In 2020, approximately one-quarter of all Americans consumed plant-meat, and in a 2021 survey, 41% of respondents indicated they were likely to purchase some plant-meat products, a significant increase from a similar 2018 survey in which 33% of respondents indicated this inclination.

US-based corporations have been at the forefront of global plant-meat product development. This includes both some of the biggest plant-based start-ups (e.g., Beyond Meat, Impossible Foods) as well as some of the world's largest livestock processing TNCs which also produce plant-meat, such as Tyson (Raised & Rooted) and Hormel (Happy Little Plants). The success of these corporations has triggered large food corporations (e.g., Kellogg, ConAgra) and supermarket chains (e.g., Trader Joe's, Kroger) to acquire smaller start-ups or launch their own lines of plant-based products for consumers, further expanding the availability of plant-meat in different retail outlets.

While the growth, diversity, and mainstreaming of plant-meat products in the US clearly make substitution easier, it does not automatically point towards re-meatification, as the simultaneous growth of plant-meat and animal flesh production makes clear. This is further suggested by a 2019 survey which found that as many as 98% of the people who purchase plant-meat products also regularly consume animal flesh.

The US government has not made any commitments to decrease the extremely high levels of per capita meat production and consumption that prevail, as agricultural subsidies remain heavily concentrated on industrial monocultures and livestock operations and fail to provide support for plant-meat product development. In addition to the variety of environmental harms linked with the enormous scale of livestock production, US agricultural policy subsidizing livestock-heavy diets is also implicated in high rates of non-communicable diseases like obesity, cardiovascular disease, and type-2 diabetes, which provides further grounds for challenging this trajectory.

Source: Open World Facts (2019)

[16] This section is based upon the following sources: Good Food Institute (2021b); Howard (2021); Miao (2020); MSU (2021); Neff et al. (2018); Newton & Blaustein-Rejto (2021); Packaged Facts (2020); PBFA (2020).

Germany

Germany has relatively high rates of per capita meat consumption, but it is possible that the re-meatification of diets is already in its early stages, as demand for plant-based foods in Germany is among the highest in the world and is especially strong among younger demographics.[17] Recent surveys indicate that nearly two-thirds of German consumers describe themselves as actively working to reduce their meat consumption. It is estimated that the growing populations which identifies as flexitarian in Germany consumes approximately 4 times more plant-meat products and half the servings of animal flesh than do self-identified omnivores. In 2016, more plant-based products were launched in Germany than in any other country, and new product development remains dynamic and is steadily occupying more prominent places in supermarkets and other retail outlets.

As in the US, plant-meat product development in Germany has come from a combination of specialized start-ups (e.g., Planty-of-Meat and LikeMeat) and some of the country's largest livestock processors, such as Danish Crown (Naturli Foods), Vion (ME-AT), and Rügenwalder Mühle. The latter is especially notable, as it is one of Germany's oldest and largest animal-meat companies which only first launched plant-meat product lines in 2014, and yet by 2020 these had overtaken its animal flesh products in total sales.

Unlike in the US, the German government has openly acknowledged the importance of reducing meat consumption in pursuit of greater sustainability and improved public health. This is also reflected in some notable actions, including the fact that animal flesh is no longer served at governmental functions and some state support has been directed toward research in plant-meat product development (e.g., new extrusion technologies to enhance the texture of plant-meat products).

Source: Open World Facts (2020)

[17] This section is based upon the following sources: Agrosynergie (2018); Bielinska et al. (2020); Bryant et al. (2020); Destatis (2021); LikeMeat (2021); MarketLine (2019b); Michel et al. (2021); Planty-of-Meat (2021); Schäfer (2020).

China

China has been at the forefront of global increases in animal flesh production and consumption since the 1980s yet it also has a long history and strong tradition of plant-meat production and consumption.[18] A 2018 survey found that as many as 87% of Chinese consumers have eaten plant-meat, which is a significantly higher proportion than most HICs, including the US and Germany.

Commercial plant-meat product development in China has predominately come from medium-sized companies and was bolstered by the 2016 government announcement pointed to the importance of cutting the per capita consumption of animal flesh in half by 2030 on environmental and public health grounds, following decades of explicit encouragement of increased consumption. Leading start-ups involved in plant-meat product development include Whole Perfect Food (Qishan), Starfield, Hey Maet, and Zhenmeat.

China is also viewed as a leading market for plant-meat exporters based in other countries, in spite of the burgeoning domestic producers and the fact that some prominent plant-meats like burgers and sausages do not have the same resonance in Chinese food cultures. Fast-food chains are an important vehicle for this growth. For instance, Beyond Meat sells various plant-meat products in Starbucks cafes in China and in 2021 opened a new production facility in China, and Cargill's PlantEver chicken substitutes are sold at KFC fast-food restaurants which are common in many Chinese cities.

China is a major producer of a number of important crops used in plant-meat, including soybeans and wheat, as well as smaller protein-rich inputs like konjac and edible fungi. In 2018, non-genetically modified soybeans were the key ingredient used in three-quarters of plant-meats produced in China, most of which were domestically produced, and China has a high capacity for processing soy protein isolate and textured soy protein.

The extent to which the Chinese government championed rising animal flesh production in recent decades might have denigrated the perceptions of soy-based plant-meats for some people. However, new regulatory standards for plant-meat retailing were established in 2020, geared to ensuring the quality and uniformity of products and labels, and this could help to dispel some negative connotations and food safety concerns.

Source: WEMP (2019)

[18] This section is based upon the following sources: Chinese Nutrition Society (2016); Lim (2021); Siu & Miao (2018); Yuan (2020).

Brazil

The per capita consumption of animal flesh in Brazil has risen dramatically in recent decades and plant-meat products development and retail growth are in their early stages.[19] However, from 2012 to 2016 the introduction of new plant-based products grew at a rate more than twice as fast as the world average. In a 2018 survey of Brazilian consumers, nearly one-third of respondents described themselves as striving to reduce their meat consumption, and a 2020 survey found that more than half of all respondents were willing to replace their consumption of animal flesh with plant-meat.

The growth of plant-meat production in Brazil is largely coming from large livestock TNCs rather than specialized plant-based start-ups, although the recent success of some emerging companies (e.g., The New Butchers and Future Farm) may signal this is changing. As noted earlier, Brazilian-based JBS is the world's largest meat processor, and it has recently introduced a range of plant-meat products through its Seara and OZO brands. Marfrig is another Brazilian-based livestock-processing TNC developing some plant-meat product lines, including a plant-meat burger that is sold as the 'Rebel Whopper' in Burger King restaurants in some Brazilian cities. US-based TNCs are also seeking to increase plant-meat exports to Brazil.

In addition to its technologically sophisticated livestock sector, Brazil is also home to many other large food processing TNCs. There are extensive resources devoted to food sciences and product innovation within Brazilian corporations, state agencies, and universities that could be marshalled for plant-meat product development. One indication of this potential can be seen in the Biomas Project, which funds research exploring the potential to utilize plant proteins from species natives to Amazonia, which could ultimately provide valuable ingredients for plant-meat products.

The potential for re-meatification in Brazil could be enhanced by the primacy of beef among other animal flesh in the dominant food culture given that plant-based substitutes are presently most advanced with beef, both within Brazil and among foreign-based plant-based start-ups like Beyond Meat and Impossible Foods. Beef substitutes are the most commonly consumed plant-meat products in Brazil, and the ease of substitution with things like plant-based burgers and ground-beef is clear.

Source: Vegconomist (2020)

[19] This section is based upon the following sources: Beyond Meat (2020); Gallon (2021); GlobalData (2020); Good Food Institute (2018); Vendemiatti (2020).

India

Although India has a massive population with a large number of vegetarians, plant-meat product development and availability are relatively limited, and there are only a few domestic companies that offer products which are distinct from more generic, unflavoured foods like tofu, tempeh, and dehydrated soy chunks.[20] Both the modest level of per capita meat consumption and scale of vegetarianism suggest that demand for plant-meat products could grow quickly. This potential is further suggested by a 2018 survey of Indian consumers, where nearly two-thirds of respondents indicated a willingness to regularly purchase plant-meat, and other research which indicated that Indian consumers, on average, tend to view plant-meat more favourably than do consumers in either the US or China.

Unlike the US, Germany, China, and Brazil, large livestock processing corporations in India have as yet shown little interest in developing plant-meat products. However, there are a few plant-meat focused companies that have arisen and dominate the fledging Indian market in plant-meats, such as Veggie Champ, Vegeta Gold, Vezlay, and Imagine Meats, with soybean the primary ingredient used in most products. One barrier to the diffusion of these product lines is the limited cold storage infrastructure that prevails across much of rural India, which is a significant reason why the availability of plant-meat products is much greater in Indian cities.

As discussed earlier, India has among the lowest levels of per capita meat consumption of any country, influenced in part by the objection to cattle flesh among the Hindu majority and the objection to pig flesh among the Muslim minority. There are also widespread protein deficiencies, especially in rural areas, which relate to poverty, inequality, and access to food in general rather than animal products specifically. In addition to the environmental benefits of plant meats relative to animal flesh, the growth of plant-meat products in India could also better respond to protein deficiencies than expanded livestock production as it involves more efficient use of plant protein.

Source: TradeMubarak (2021)

[20] This section is based upon the following sources: Arora et al. (2020); Best (2020); Bryant et al. (2019); Deshpande (2020).

Nigeria

Plant-meat is not very common in Nigeria, although some Nigerian plant-based start-ups (e.g., VeggieVictory) and livestock processing companies (e.g., Chi Farms Ltd.) have recently introduced some new plant-based product lines.[21] Reflecting this lack of availability, consumer research indicates that few people in Nigeria are aware of plant-meat and other plant-based livestock substitutes. Nevertheless, there is a small but growing plant-based movement, particularly in large cities like Lagos, Kano, and Ibadan.

Crop production is generally difficult in the semi-arid and arid regions of northern Nigeria given the long dry periods and short-rain seasons, which is being made worse by climate change. However, certain protein-rich crops have a long history of cultivation in semi-arid and arid regions in West Africa, including various legumes (e.g., groundnuts, cowpeas, pigeon peas, Bambara beans) and these could be good candidates for future plant-meat product development in Nigeria.

Similar to India, Nigeria's cold storage infrastructure is under-developed, especially in rural areas, which presents a significant barrier to imports of plant-meat products and either foreign or domestic investment in plant-meat production. At present, Nigeria's agro-food sector also lacks the sort of technological capacity for processing that is used in some plant-based products.

In addition to the limited availability of plant-meat products in retail outlets, consumer awareness about their desirability is further inhibited by public health guidance promoting increased meat consumption as a key part of reducing malnutrition. Further, the Nigerian government provides few agricultural subsidies in general, and it is implausible to envision it having any significant role in the development of plant-meat products at any point in the near future.

Source: Flutterwave (2021)

[21] This section is based upon the following sources: Ajadi (2018); Chi Farms (2020); George (2020); Good Food Institute (2021a); Makanjuola (2021); Omoigui et al. (2020); Research and Markets (2018).

Fostering Re-Meatification

A central premise of this Guidance Memo is that the meatification of diets causes many environmental harms and this course of dietary change must be contested and reversed. Put simply, *de-meatification is imperative to any hope of building more sustainable, equitable, and humane agro-food systems.* This memo aims to help environmental and animal advocates understand and communicate the important role that plant-meats can potentially have in encouraging rapid de-meatification in HICs and UMICs, as well as in limiting future meatification in lower income countries.

However, it is important to recognize that this potential is not inherent in the growth of plant-meat production and consumption. On the contrary, it is possible for plant-meats to increase concurrently with increases in animal flesh, and preliminary research suggests this simultaneous growth is occurring in a number of countries. Thus, the transformative potential of plant-meat hinges on the progressive substitution for animal flesh—what we refer to as the *re-meatification* of diets. While it is too early to assess the correlation between plant-meat and animal flesh in any definitive way, the surge of plant-meat in Germany alongside declines in per capita animal flesh consumption gives one hopeful indication about the prospects for substitution.

This memo placed considerable emphasis on the enormous disparities in the production and consumption of animal flesh on a world scale, and the multidimensional environmental problems this entails, because these are essential starting points for communicating the significance of de- and re-meatification. Efforts to promote plant-meat production and substitution in diets must be sensitive to very different present consumption levels, food cultures, and political economic contexts. The latter entails recognizing the incredibly powerful vested interests associated with industrial livestock production, including their growing presence in plant-meat production.

Attention to global disparities in the production and consumption of animal flesh makes it clear that efforts to promote re-meatification is most urgent in HICs and UMICs. In lower income countries, efforts to promote re-meatification should stress that plant-meats provide a way to avoid the industrialization of livestock production and its many problems—a grave mistake associated with modern development rather something that should be emulated.

Environmental and animal advocates must strive to demystify meatification, stressing that the production and consumption of animal flesh is not inevitably bound to increase with rising wealth, and that industrial livestock production is an extraordinarily inefficient and unsustainable way to produce protein-rich foods. Related to this, the progressive substitution of plant-meats in diets should be conveyed to consumers as a way of securing protein-rich foods more efficiently, emphasizing that they require far less land, on average, than animal flesh because they avoid the opportunity food losses that inhere in livestock production.

While there are some universally applicable messages for promoting re-meatification, there is no single strategic blueprint. In HICs and UMICs, the enhanced efficiency of deriving nutrition directly from plants should be conveyed first and foremost in terms of climate change, biodiversity loss, and the potential for ecological restoration. In low-income countries, where food insecurity in most pervasive, it is more important for messaging to convey the potential to enhance protein availability by processing plants directly into meats rather than cycling them through animals.

In countries like the US, Germany, and Brazil, where high levels of per capita animal flesh consumption are deeply entrenched in cuisines, daily routines (such as the prevalence fast food), and food preparation skills, increasing plant-meat production—and improving its resemblance to the taste and texture of flesh in its most ubiquitous forms—constitutes the most plausible mechanism to speed large-scale dietary change. In countries like China and India, advocacy about the environmental merits of plant-meats should connect this to the rich history of diverse plant-proteins in these food cultures, including the household production of plant-meats in China.

Related to this, it is important that plant-meat product development is not simply defined by the sort of growth unfolding in HICs, concentrated on products like burgers, sausages, nuggets, and cold cuts, and that plant-meat product development is tailored to diverse food cultures and food preparation skills. For example, pork consumption is at the forefront of meatification in China, and it is notable that several plant-meat companies are developing pork substitutes directly oriented to the Chinese market.

Along with outreach geared to affecting consumer decisions, environmental and animal advocates should also seek to educate and lobby governments for policies that promote greater plant-meat production and consumption. Some key dimensions of this policy-oriented advocacy include urging governments to:

- shift agricultural subsidies away from livestock production, including crops used as feed, and towards inputs for plant-meat products (while there is some overlap here, most notably soybeans, subsidies could be made to hinge on the end use of crops);
- devote more public research capacity (from ministries of agriculture to universities) away from livestock production and towards plant-meat research and development, with an emphasis on developing culturally appropriate substitutes;
- provide direct financial support (e.g., subsidies) or indirect incentives (e.g., tax breaks) for corporations pursuing research and development in plant-meat products, such as processing techniques that synthesize elements in new ways;
- give a prominent place to plant-meats in nutritional guidance about protein consumption;
- increase the rigour of product labelling demands with respect to environmental impacts and animal welfare conditions.

Obviously, calling upon governments to reorient subsidy regimes away from feed crops and industrial livestock production runs directly counter to very powerful vested interests. This includes both the interests that governments have in strong agro-export performance, and the deeply embedded relationships that TNCs have with governments, such as Tyson and Cargill in the US, JBS and Marfrig in Brazil, and the WH Group in China. However, as this report has indicated, TNCs focused on livestock processing are making strong moves to develop or acquire plant-meat product lines, and its possible that a reorientation of subsidy regimes could act as a spur that drives more a significant restructuring of their business models, as well as enhancing the cost-competitiveness of plant-meats.

The increasing engagement of many large livestock processing TNCs in plant-meat production should not be read with either excessive pessimism or optimism about how it might impede or advance re-meatification. Instead, caution is in order, as however powerful they might be in shaping consumer demand, there are limits to this, and ultimately, they must also be responsive to changes beyond their control. At the same time, it must be recognized that the entrenched interests in the profitability of livestock production clearly limits the scope of marketing initiatives that will accompany their plant-meat product lines. This places a great onus for education and outreach on environmental and animal advocates, as well as entirely plant-based enterprises, to convince both consumers and governments of the merits of plant-meat and the urgency in facilitating the re-meatification of diets.

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Appendices

Appendix A: Some key policy dimensions influencing livestock production in the case studies

United States

The US government actively supports livestock production through the subsidization of infrastructure (e.g., irrigation systems) and various services (e.g., insurance programs, price supports, export agencies) that are heavily directed at feed crops. This subsidization also encourages excessive production beyond what US livestock can absorb, as the US is one of the world's largest exporters of soybeans and maize, mainly to China, Japan, and Germany. Both direct and indirect subsidies serve to increase livestock production and meat consumption by artificially deflating production costs and consumer prices. By one estimate, meat products in the US would cost *at least* three times higher than they do in the absence of all government subsidies, without considering the unaccounted environmental costs—which arguably constitute another massive implicit subsidy.

Germany

As a member of the European Union (EU), Germany's livestock production is heavily affected by the Common Agricultural Policy (CAP). The CAP entails extensive government supports for livestock producers, including direct income payments to livestock producers based on farm size and the number of animals, which has contributed to the increasing industrialization, especially of pigs and chickens. The CAP has also long subsidized feed crop production as well as allowing for the cheap importation of feed crops. As in the US, the cheapness of feed effectively deflates the cost of meat. Meat consumption is further encouraged by market measures, notably a significantly lower value added tax (VAT) rate of 7% on meat products compared to the general VAT of 19% for other retail sales.

China

While the state provides few direct subsidies for livestock farmers, it has actively supported dragon-head enterprises that in turn promote industrial techniques in a variety of ways, including through their control over livestock breeding and the provision of inputs such as feed and pharmaceuticals. The liberalization of feed imports is another very significant way the Chinese state has supported the industrialization of livestock. China's industrial livestock operations are the reason why it is the world's leading importer of soybeans, commanding about two-thirds of available global soybeans annually, mostly imported from southern South America and the US. China recently liberalized markets for imported meat products, but its imports and exports of meat are very small relative to total production and consumption.

Brazil

The Brazilian government has long subsidized the livestock sector in a range of ways. The National Champions policy existed from 2007 to 2013 and was geared to promote the increasing export-orientation of TNCs through a range of direct and indirect subsidies, such as tax incentives, subsidized credit, and debt forgiveness.

The socio-cultural value of meat-eating in Brazil is partly rooted in its colonial past, including the importance of cattle in expanding the agricultural frontier and the strong attachment to beef among Portuguese settler-colonialists. In modern times, the Brazilian state has continued to champion the role of cattle in transforming land for human settlement, most destructively in Amazonia from the 1960s onwards. The state has also venerated meat consumption in nutritional guidelines, while the central place of meat at barbeques in family and community gatherings further helps normalize meat-eating.

India

Since the 1950s, the Indian government provides has subsidized various farm inputs, including the development of irrigation infrastructure, the distribution of high-yielding seed varieties and fertilizers, and the provision of tractor services, as well as operating state marketing boards and storage systems for key crops. However, government supports tend to skew towards medium- to larger-sized farms, while the vast majority of the country's large agricultural population has long received minimal support. The Indian government has not made significant investments in the livestock sector, apart from subsidizing the modernization of livestock slaughter and processing facilities—largely with respect to chickens—with the goal of increasing food safety for domestic markets and enhancing the capacity for export growth.

Nigeria

The Nigerian government recommends increased meat consumption in its national nutritional guidelines—which it argues can help alleviate malnutrition (which obscures the fact that improving access to plant-based foods can respond equally well to the problem of malnutrition, which is rooted most of all in poverty and insufficient effective demand). Recommending increased meat consumption inherently means increasing livestock production, which will have devastating effects on the environment in Nigeria. The government has had a role here: traditional herding was significantly altered by large-scale enclosures of land during the period of British colonial rule, from the late 19th century to 1960, and following independence. Although the Grazing Reserve Act (1964) sought to protect some of the pathways and grazing areas for migratory herders, human population growth and expansion of towns, cities, roads, farms, ranches, and mines have greatly complicated the practices of herding cultures. In 2018, Nigeria's government enacted the National Livestock Transformation Plan which further encouraged the transformation away from shifting pastoralism towards sedentary ranching, as it created nearly 100 large ranches without allocating land or protecting more corridors for migratory herders.

Appendix B: Leading TNCs in the livestock sector in the case studies

United States

The livestock processing sector in the US is highly concentrated, dominated by a few powerful TNCs. The four-firm concentration ratio assesses the market share held by the top four firms in any given market and is extraordinarily high in US meat processing; in 2016, this was assessed to be 85% for beef (Tyson, JBS, Cargill, National Beef); 66% for pork (WH Group, JBS, Tyson, Hormel); and 51% for chicken broilers (Tyson, JBS, Sanderson, Perdue). Tyson Foods is the largest livestock processor in the US, controlling 20% of the beef, pork, and chicken produced by volume, as well as having operations in various countries in Asia and Europe.

Germany

Similar to the US, the growing scale and industrialization of livestock production in Germany has gone hand-in-hand with increasing market concentration in livestock processing. Four TNCs control about two-thirds of the meat processing sector in Germany—Tönnies, Vion, Westfleisch, and Danish Crown—with Tönnies the biggest, specializing in cattle and pigs.

China

The biggest TNC to emerge from the rapid industrialization of livestock production is the WH Group, which is by far the largest meat processor in China. In 2013, the WH Group purchased US-based Smithfield Foods, making it the world's largest pork processor with facilities not only in China and the US but in many other countries. New Hope Liuhe is China's largest poultry processor, and like the WH Group it has quickly grown into a global-scale actor, with operations in 20 countries. These TNCs have grown through a combination of domestic and foreign acquisitions (horizontal integration) and through vertical integration, with interests not only in animal slaughter and processing but other aspects of production like the supply of livestock feed.

Brazil

Brazilian finance capital has had an important role in the dramatic expansion of the largest Brazilian-based meat processors—JBS, Brasil Foods (BRF), and Marfrig—which have aggressively pursued acquisitions within and beyond Brazil, including some large US-based meat processing TNCs. JBS and BRF control approximately half of all Brazil's poultry and beef processing by volume, and JBS is the world's biggest meat processing corporation. While China-based TNCs have acquired a degree of control over soybean production through acquisitions of agricultural land in Brazil, the Brazilian government strongly regulates against foreign ownership in livestock processing.

India

Corporate power in livestock processing and slaughter in India is mainly concentrated in the poultry sector. Two large Indian-based TNCs have emerged with the growth of poultry and livestock feed: Venkateshwara Hatcheries (VH Group or Venky's) and Godrej Agrovet, with the latter merging with US-based Tyson Foods in 2008 to form Godrej Tyson Foods Ltd.

Nigeria

The increasing intensification of poultry-production is entwined with the emergence of some poultry-oriented corporations, including the NatnudO Group—a vertically integrated corporation overseeing hatcheries, pharmaceuticals, feed mills, processing plants, and managing thousands of semi-independent farmers.